

Mines and Minerals Branch Report of Activities 1987, Part B

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Editors

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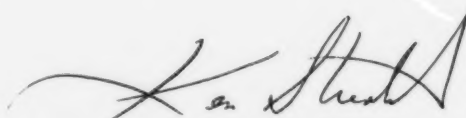
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FOREWORD

This report presents the results of a variety of projects carried out or coordinated by the Nova Scotia Department of Mines and Energy in 1987. The Provincial and Federal governments are partners in the orderly exploration for and development of Nova Scotia's mineral resources through a program of mineral development. The vehicle of this joint program is the five-year Canada - Nova Scotia Mineral Development Agreement implemented in 1984. Many research projects funded through this agreement are nearing completion and are able to supply detailed information to representatives of the mineral industry. Through this co-operative effort, workers from within the Department are able to collaborate with Energy, Mines and Resources Canada, the university community, and other colleagues to accomplish ambitious research goals.

Gold exploration and development continued to be the highlight of the Nova Scotia mineral industry in 1987. This predominance is reflected in the large proportion of this volume dedicated to gold research. Continuing work on the Province's coal resources reflects the long-term importance of coal to the Province and its people. A variety of other mineral resources have been examined and results from this work are described in this report. Also prominent are regional geological and geochemical surveys to evaluate the mineral potential over large areas of the Province. These activities expand the information base available to the resource sector and strengthen our resource industries.

I commend this publication to your attention on behalf of the staff of the Department of Mines and Energy. This report presents the considered interpretations and conclusions of research at an advanced stage of project development. Our intention is to provide information that will help you understand Nova Scotia's geology and mineral resource potential.



Honourable Ken Streatch
Minister of Mines and Energy



PETROLEUM RELATED ACTIVITY OFFSHORE AND ONSHORE

G. P. van Heuven

Although the worldwide downturn in oil and gas drilling activity was felt in Nova Scotia, a number of significant events took place.

OFFSHORE

RESOURCE MANAGEMENT

In May 1987 the Nova Scotia Legislature approved a package of legislation to enable the implementation of the Canada-Nova Scotia Offshore Petroleum Resources Accord that was signed in August 1986. The Federal Government has introduced a similar package of legislation to the Parliament of Canada.

The Accord provides Nova Scotia with several significant improvements over the 1982 Offshore Agreement it supersedes. It gives Nova Scotia full control over provincial revenues as if the resources were on land and provides greater provincial control over the management of offshore activities.

Under the Accord the Province has singular jurisdiction over royalties for the offshore. The basic elements of Nova Scotia's Offshore Petroleum Royalty Regime were announced in 1987. Nova Scotia's objective in designing the royalty regime was to create a system which would help produce an attractive rate of return, adequate cash flow and fiscal stability for industry investors, while ensuring Nova Scotia a fair economic return and encouraging recovery of marginally economic reserves. Based on these objectives, the following royalties for the offshore were developed:

Before Project Payout

. A base royalty equal to 2% of gross wellhead revenues; and

After Project Payout

. A royalty equal to 30% of the net profits before tax with the minimum royalty equal to the base royalty.

OFFSHORE ACTIVITY

At the end of 1987, 648 567 hectares were held under active exploration agreements, all in the vicinity of Sable Island. This is a reduction of 397 803 hectares from year end 1986, due to surrenders and exploration agreements reaching the end of their terms. At the end of these active exploration agreements, all lands will revert to the Crown except those held by a declaration of significant discovery.

In addition to the lands held under active exploration agreements, federal exploration permits were issued in the 1960s for Georges Bank and areas adjacent to the Nova Scotia-Newfoundland boundary. Drilling is currently not permitted on Georges Bank due to concerns about the impact of drilling on the fishery. There is a moratorium on activity on lands adjacent to the Nova Scotia-Newfoundland boundary due to an international boundary dispute between Canada and France over the extent of the French territorial zone associated with the Islands of St. Pierre and Miquelon. Figure 1 depicts the lands held by exploration companies at December 1987.

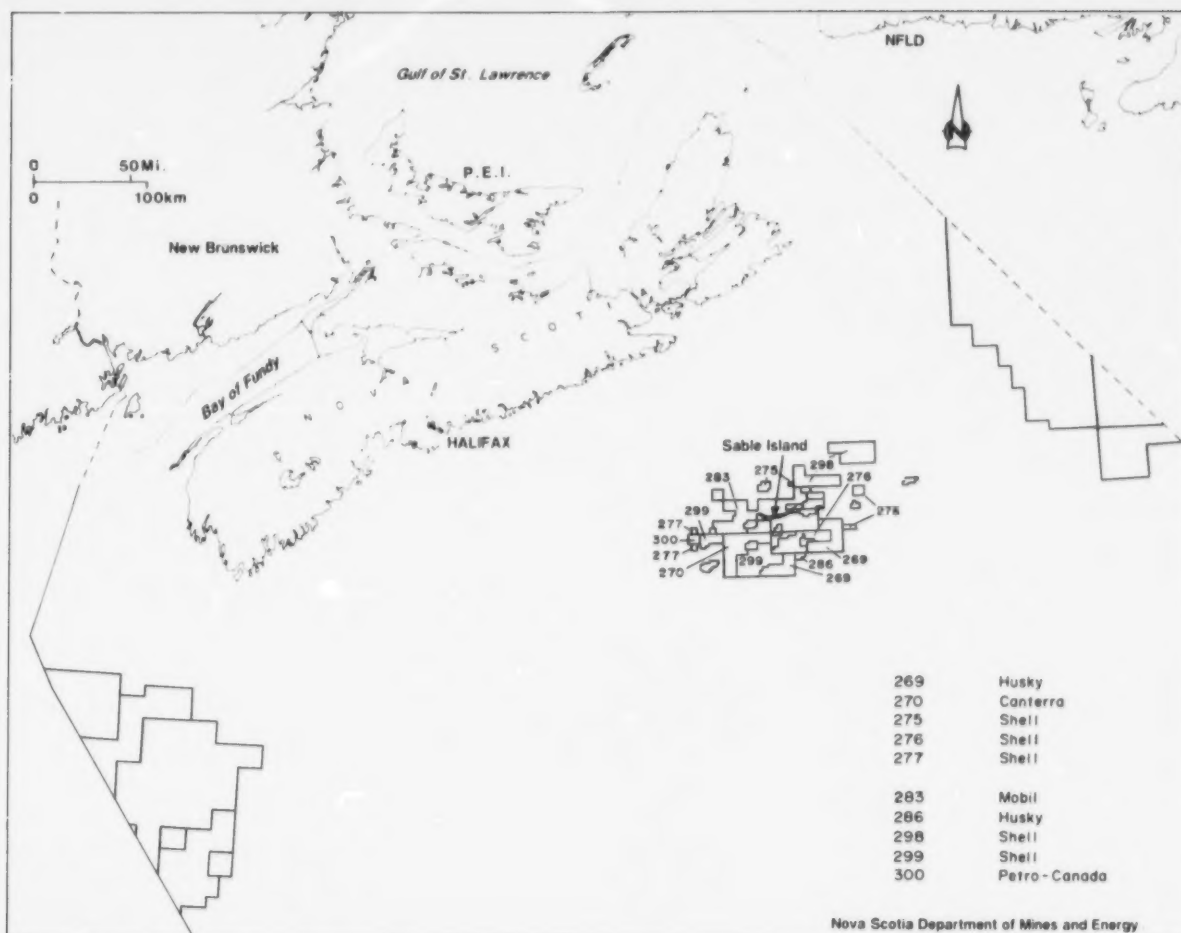


Figure 1. Negotiated offshore Nova Scotia exploration agreements.

Three wells were spudded and completed in 1987. Canterra drilled the Whycocomagh N-90 wildcat well with the semi-submersible Sedco 710. The well tested a potential gas structure, however, no significant hydrocarbons were encountered. Petro-Canada drilled the wildcat well, Como P-21, in a potential oil structure west of the Cohasset oilfield and northwest of the Panuke B-90 oil discovery. No oil was discovered and the well was abandoned. A delineation well drilled on the Panuke structure, Panuke F-99, was spudded during July. The western extent of the Panuke reservoir was determined by a drilling program in which three tests were conducted. A

unique 6-day testing procedure produced 4,000 barrels per day (635 m³) and used a tanker to collect high quality oil. The oil was then shipped to the Petro-Canada refinery in Montreal for refining and further testing. This was the first shipment of crude oil from Canada's East Coast offshore.

At year end, the 124th well in Nova Scotia's offshore history had been completed. Of these wells, 71% have been wildcats (the first well drilled on a new geological feature) and 29% were delineation wells (to evaluate discoveries already made). Seventeen significant natural gas finds and four significant oil discoveries have been

recorded since drilling first began.

ONSHORE

RESOURCE MANAGEMENT

Two-thirds of the land previously held was carried over in 1987 under renegotiated exploration agreements concluded with Chevron Canada Resources Limited and Irving Oil Limited, Sigma Resources, Inc., and Miles et al. Sigma Resources elected not to continue into the second year of their agreement and surrendered their land in April 1987. In 1987 the Province received \$189 607 in rent under the active

exploration agreements. Current exploration agreements are shown in Figure 2.

The search for oil and gas onshore has concentrated on Carboniferous rocks that underlie approximately one-third of the Province or 1.8 million hectares. Although numerous shows of oil and gas have been encountered, no commercial discoveries have been made.

The Department received several recent requests for information from parties interested in acquiring exploration rights onshore. A Call for Proposals may be held if these

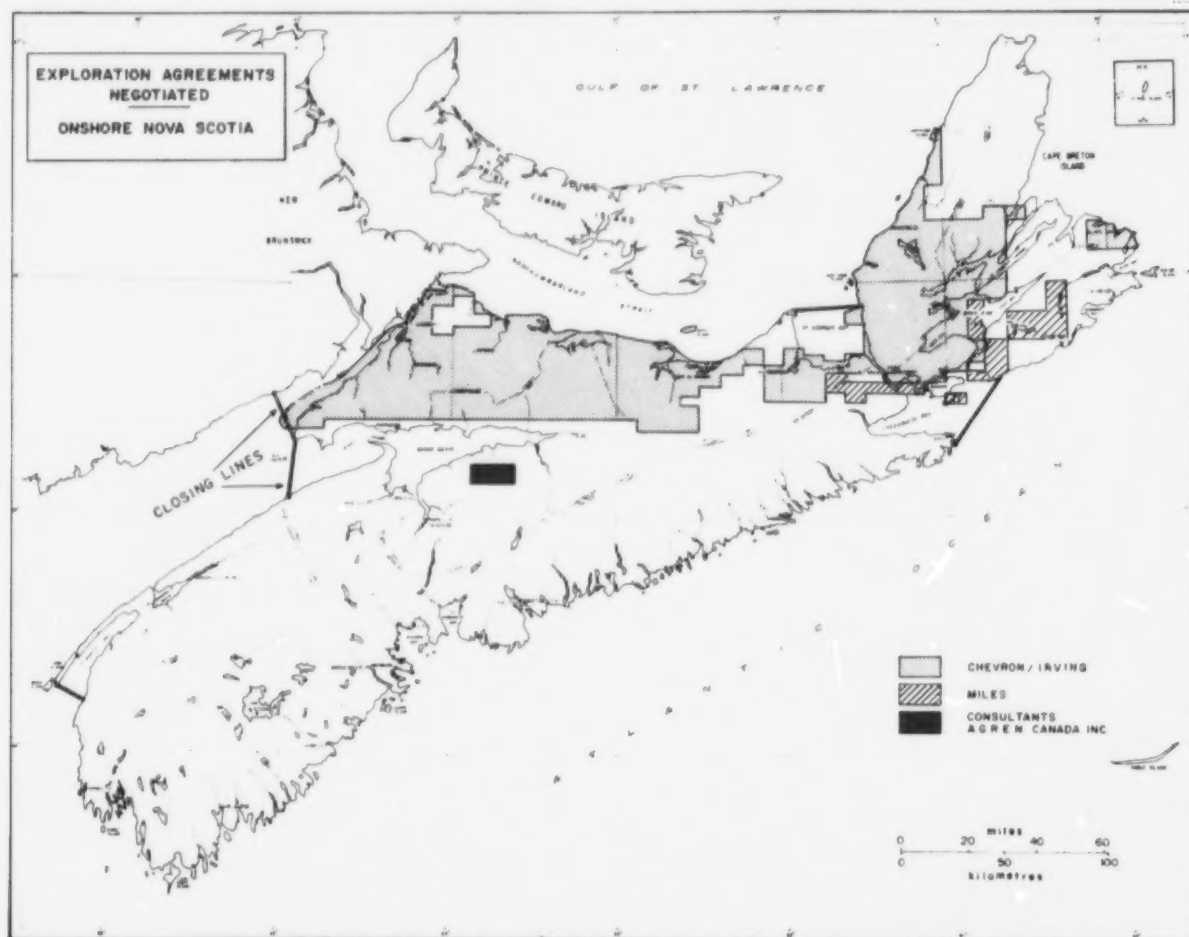


Figure 2. Negotiated onshore Nova Scotia exploration agreements.

companies, or others, decide that they wish to obtain exploration agreements. Such a call would be the first issued under the Petroleum Resources Act.

The Department, through funding by the Canada - Nova Scotia Mineral Development Agreement, is undertaking a study of the petroleum source rock potential. This study, which is scheduled for completion in the spring of 1989, is intended to identify

regions of the Province that are most promising for petroleum exploration.

The Petroleum Resources Act provides for the management of Nova Scotia's coal gas resource. Coal gas regulations were promulgated December 1, 1987. Negotiations for coal gas agreements are underway and must be concluded by May 31, 1988, to keep previous coal gas rights in good standing.

REPORT ON NEW CAMPBELLTON COAL DISTRICT, VICTORIA COUNTY: CORRELATION AND COAL RESOURCE POTENTIAL

D. J. MacNeil

INTRODUCTION

The New Campbellton coal district (MacKay, 1947) represents the westernmost exposure of the Morien Group coal-bearing strata in the Sydney Basin (Boehner and Giles, 1986). Morien Group rocks are in fault contact with older Carboniferous rocks and pre-Carboniferous basement rocks of the Kellys Mountain Block. The Mountain Fault is a major fault which marks the western (on-land) limit of the Sydney Basin/Sydney coalfield (Fig. 1). The New Campbellton district is separated from the rest of the Sydney coalfield by the 1-2 km wide mouth of the Great Bras d'Or. This isolation, along with limited outcrop, facies changes and deformation associated with the Mountain Fault, has meant that the detailed stratigraphy, particularly the correlation of the coal seams, has not been clear. Recent work in the area was undertaken to clarify the geology of the local coal measures, their relationship to the rest of the Sydney coalfield, and to assess the coal resource potential of the area.

Coal mining was first reported at New Campbellton in 1862 (Nova Scotia Department of Mines, 1863). Deformation of strata adjacent to the Mountain Fault resulted in a near-vertical inclination for the coal seams and the initial production (C. J. Campbell mine) was from adits driven into the base of the mountain to intersect these seams. The mines were worked intermittently for the next 75 years, with several new slopes opened on the "Fourfoot Seam" south of the original adits. No. 1 Slope was begun in 1866, No. 2 Slope in 1904 and No. 3

Slope in about 1919. The largest reported yearly production was 14 985 tonnes in 1896. Total reported production from the district is about 174 000 tonnes (Millward, 1985).

The sporadic mining activity resulted from several factors: the thinness of the seam compared to those worked elsewhere in the coalfield, the poor quality of the coal and the relative isolation of the district. Various operators appear to have had limited resources so development was rather haphazard. As a consequence, records of the operations are scarce except for notes in *Annual Reports of Mines* for Nova Scotia.

GEOLOGICAL SETTING

The regional geology of the New Campbellton area was first outlined by Robb (1876) with revisions by Fletcher (1899) and Bell (1923). Bell's work includes a perceptive analysis of the geology of the local coal deposits.

The coal-bearing Morien Group occupies an asymmetric syncline at New Campbellton. The synclinal axis parallels the Mountain Fault about 1 km to the west (Fig. 2). Movement along this fault has thrown older Carboniferous (Windsor/Canso Group) rocks and a Cambrian-Precambrian basement block into contact with the Morien Group. Bending of strata adjacent to the Mountain Fault has resulted in a near-vertical dip for the western limb of the syncline. Dips in Morien Group rocks decrease to 15° within 0.5 km of the fault trace and show the normal subdued (about 5°) dips characteristic of the Sydney Basin at

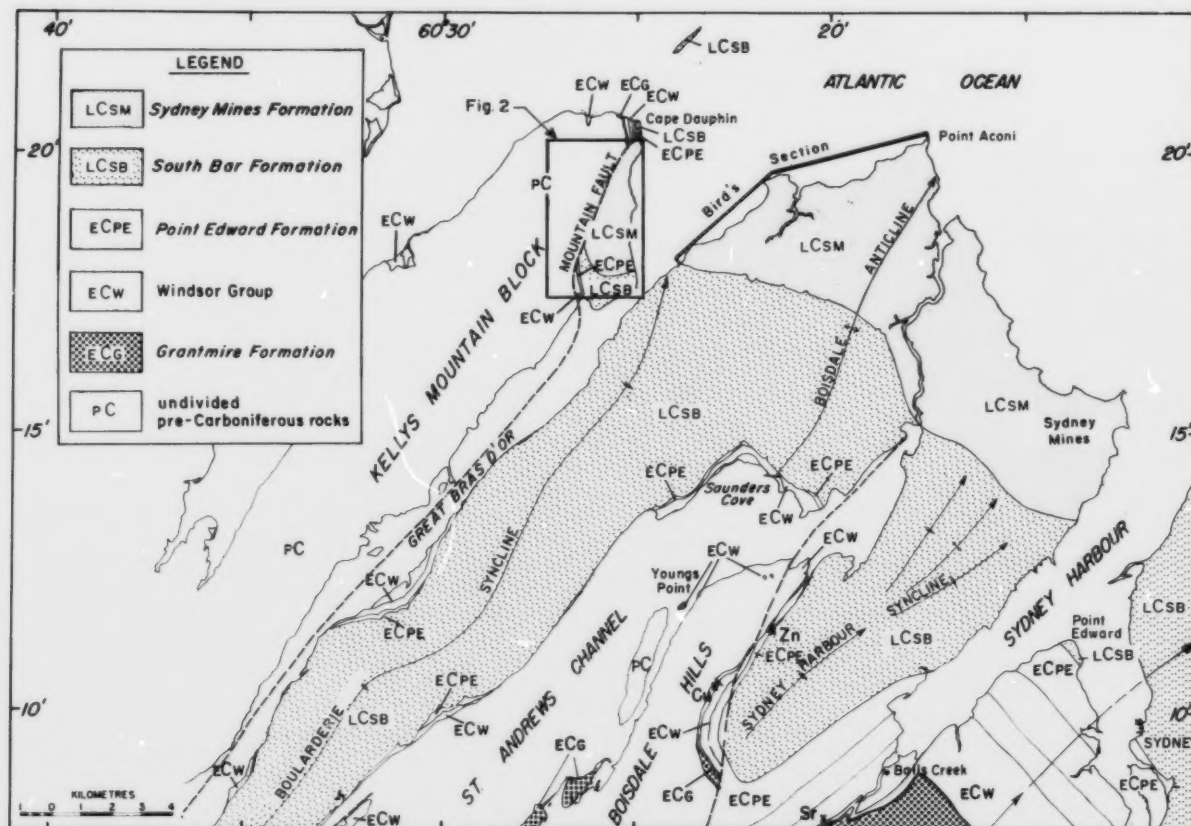


Figure 1. Geological map - northwestern onshore Sydney Basin (after Giles 1983). New Campbellton coal district is outlined by rectangle labelled Fig. 2.

the shore of Great Bras d'Or. It is inferred that the local synclinal structure is a feature superimposed on the regional pattern of gentle folding by significant post-Carboniferous movement on the Mountain Fault.

The section of Morien Group strata at New Campbellton includes the South Bar Formation, dominantly consisting of grey sandstone and pebbly sandstone (Boehner, 1984), and the lower part of the overlying Sydney Mines Formation, consisting of mudrock, sandstone and coal. At Cape Dauphin the profound basal Morien Group unconformity with the Canso Group (Cape Dauphin Formation) is exposed in a fault slice. The stratigraphic sequence of Morien Group coal seams is shown in Table 1.

Only the lower one-third of the Sydney Mines Formation occurs here, therefore the seams that were most productive in the Point Aconi and Sydney Mines districts to the east (Harbour Seam and above) do not exist at New Campbellton.

CURRENT PROGRAM

The geology and mining history of the New Campbellton district have been reviewed recently. To clarify stratigraphy and structure and to aid coal resource evaluation, core hole NC-87-1 was drilled in 1987 near the axis of the New Campbellton Syncline. The drillhole penetrated the lower Sydney Mines Formation and continued through a substantial section of the upper South Bar Formation. The hole was

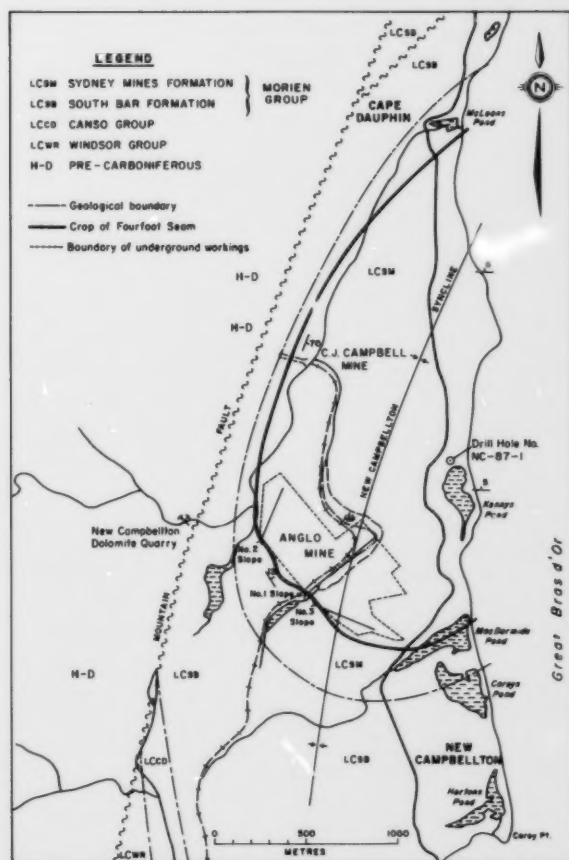


Figure 2. New Campbellton coal district, Victoria County, Nova Scotia.

geophysically logged (gamma and gamma-gamma density) and coal intersections were sampled for chemical analysis and organic petrography.

SYDNEY MINES FORMATION

Drilling results indicate that the section of Sydney Mines Formation strata preserved in the New Campbellton Syncline ranges from the Bouthillier Seam interval down to the base of the Formation, considered to be the Stony (Emery?) Seam horizon in this part of the basin. However, lack of clear markers above the Backpit (Fourfoot) Seam makes precise definition somewhat tenuous.

Table 1. Stratigraphic sequence of Morien Group coal seams, north-western part of Sydney Basin (after Boehner and Giles, 1986).

Murphy
Point Aconi
Lloyd Cove
Hub
Harbour
Bouthillier
Backpit
Phalen
Emery

Reliable correlation has been accomplished by comparison of the cored section to a detailed measured section of the Sydney Mines Formation along the western coast of Boularderie Island (Bird, 1987) directly across the channel and 1-2 km east of NC-87-1 (Fig. 3). The Phalen (Collins) Seam intervals, though badly split, are closely comparable. The Backpit (Fourfoot or Indian Cove) Seam, with its distinctive bivalve-bearing limestone roof, is readily identifiable in each section. The section above the Backpit Seam is a mixed, mudstone-dominated sequence with minor thin coals, correlated with the Bouthillier (Millpond-Edwards) Seam which is intensely split in this area. The New Campbellton section is generally slightly more fine grained than the Bras d'Or Section across the channel.

The most significant difference between these sections occurs in the Phalen-Backpit interval. This interval is 23 m thick in NC-87-1, whereas at Bras d'Or it has been measured at 41 m (Bird, 1987). The lithologic character of the sedimentary rocks at New Campbellton is quite different from that at Bras d'Or. The Phalen-Backpit interval in drillhole NC-87-1 is an overbank sequence of mudrock with minor fine grained sandstone. In the Bras d'Or coastal section, the interval

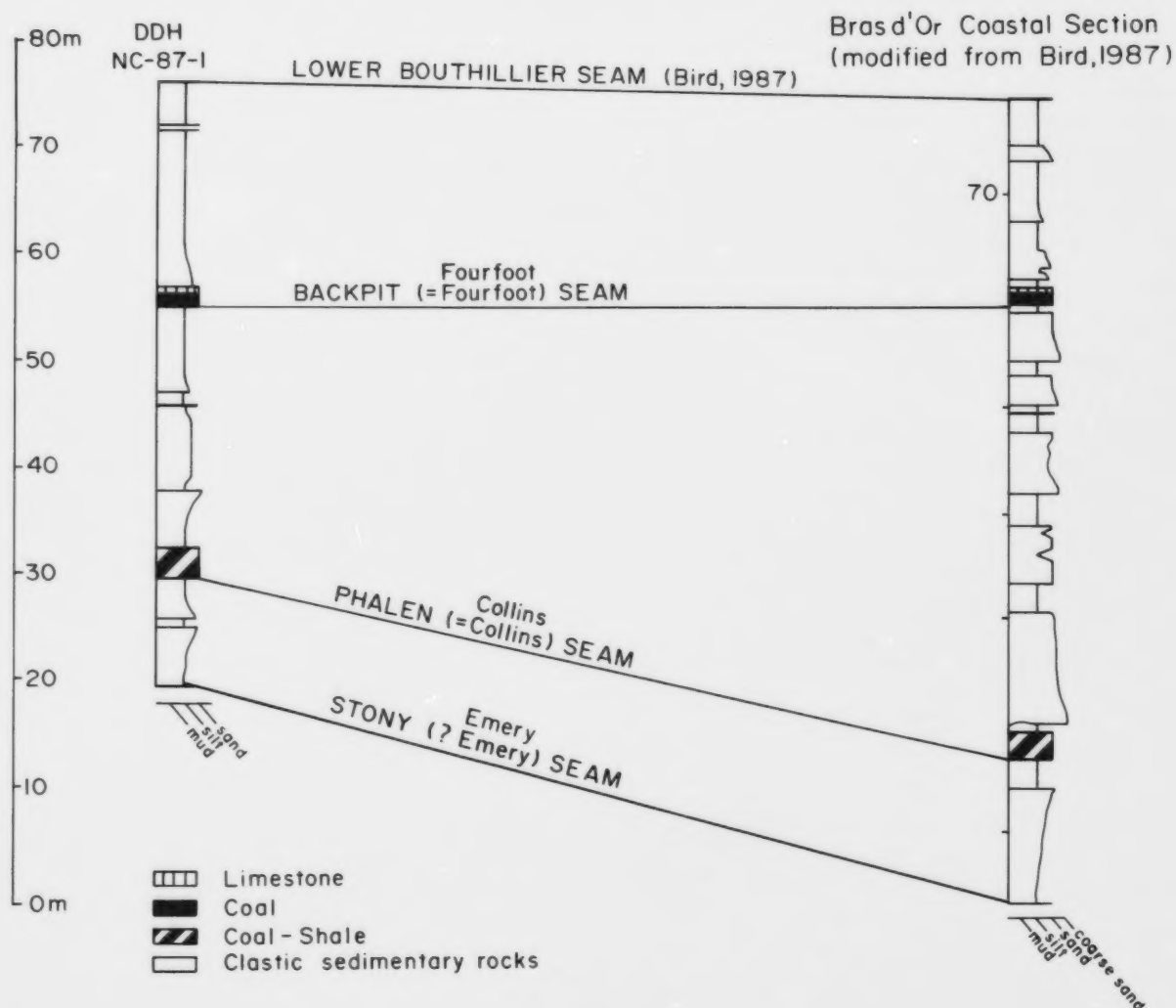


Figure 3. Stratigraphic correlation diagram, Stony Seam to Bouthillier Seam horizons, Sydney Mines Formation.

consists of thick channel deposits in the lower part with the rest of the section being a mixed, sandstone-dominated sequence of marginal channel deposits (crevasse splays - levees; Bird, 1987). If the interval in NC-87-1 represents distal overbank deposits (mudrocks) to the channel belt (sandstones) at Bras d'Or, differential compaction may account for the change in thickness. However, an approximate calculation of original depositional thickness of these intervals by "decompacting" the lithologies using

the factors of Fielding (1986), shows that only about half of the thickness discrepancy can be attributed to differential compaction. (NOTE: Fielding's decompaction factors, from observed sedimentary rocks to original sediment thickness, are as follows: peat = coal x10; clay = mudstone x2; silt = siltstone x1.5; sand = sandstone x1).

The location of the Bras d'Or section coincides with the axial region of the Boularderie Syncline (Fig. 1).

Differential subsidence along this axis during deposition of the Phalen-Backpit interval could control the locus of the channel belt. Thus, deposition of in-channel and marginal channel rocks would be maintained in the actively subsiding syn-sedimentary synclinal depression, leading to a thicker package of coarse clastics than in the more distal New Campbellton district. By the time of Backpit-peat deposition a stable regime was established, which is reflected by the consistent development of the Backpit Seam over the area. Indeed, these stable conditions were apparently basin-wide. Hacquebard and Donaldson (1969) described the Backpit seam as representing "the most continuous and widespread peat formation of the entire productive succession".

SOUTH BAR FORMATION

The South Bar Formation (Boehner and Giles, 1986) at New Campbellton consists of sandstone, pebbly sandstone, minor mudrocks and rare thin coals. Below the Sydney Mines Formation (i.e. below the Stony Seam horizon), the upper 120 m is a sandstone-dominated, mixed succession with several thin coal seams of no economic importance. One of these, intersected at 255 m in NC-87-1, may correlate with the "Henderson Seam" of Robb (1876) and Fletcher (1899). The remainder of the succession is a monotonous sequence of grey sandstone and arkosic pebbly sandstone, with fairly abundant plant remains and coaly debris.

COAL RESOURCES

The mining history of the New Campbellton district indicates two productive seams, the Fourfoot Seam and the Sixfoot Seam. Both seams were reported to have been worked in the original adit mine (C. J. Campbell Mine) near the Mountain Fault. However, the slope operations in the less structurally disturbed area of the

district to the south worked only the Fourfoot Seam. It seems clear that it was impossible to follow the Sixfoot beyond the deformed area adjacent to the Mountain Fault.

The correlation of the Fourfoot Seam with the Indian Cove (Blackrock) or Backpit Seam, proposed by Bell (1923) has been confirmed by later studies (e.g. Hacquebard and Donaldson, 1969), including current work. Bell, however, was rather circumspect in his correlation of the Sixfoot Seam. He points out that in the area of the Mountain Fault folding and faulting have given a "fictitious thickness" to the seam, i.e. it occurs in the axial region of a tight fold or has been thickened by faulting. Thus, he precluded the possibility of it being mineable beyond the influence of the fault zone. In Figure 3 (Hayes and Bell, 1923; page 101), the Sixfoot Seam is correlated with the Stony Seam at North Sydney. Interestingly, in NC-87-1 the Phalen (Collins) Seam interval is about 2 m thick and occurs at about the appropriate stratigraphic position. This confirms Hacquebard and Donaldson's (1969) correlation of the Sixfoot Seam with the Phalen Seam. However it is questionable if this was indeed the seam mined from the adit. The Phalen Seam section in NC-87-1 reveals only about 0.80 m of coal in four leaves within a 2.4 m seam interval. The so-called Sixfoot Seam, which was mined and described by Bell (1923), may simply have been a deformed fault repeat of the Fourfoot Seam within the Mountain Fault zone. Thus, only the Fourfoot (Backpit) Seam holds any potential as a coal resource. No surface mineable resource exists since much of the near surface coal has been mined from Nos. 1, 2 and 3 slopes (Fig. 2).

Based on a single control point (NC-87-1 intersection) and general knowledge of the consistency of the Backpit (Fourfoot) Seam, a tonnage classed as "speculative resource of

future interest" can be calculated for the New Campbellton district. The seam thickness observed in the drillhole barely passes the resource criteria for "underground resources of future interest" (1.03 m as opposed to a cut-off of 1.0 m; Hughes et al., in press). The Fourfoot Seam is considered to underlie approximately 120 hectares of land, giving an approximate in place resource of 1.8 million tonnes. Current technology could recover no more than 50% of this resource. Based on this relatively minor tonnage, structural complications, isolation of the district and the relatively poor quality of the coal (ash - 12.1%, sulphur - 6.91% and reported susceptibility to spontaneous combustion), this resource cannot be considered of current economic interest.

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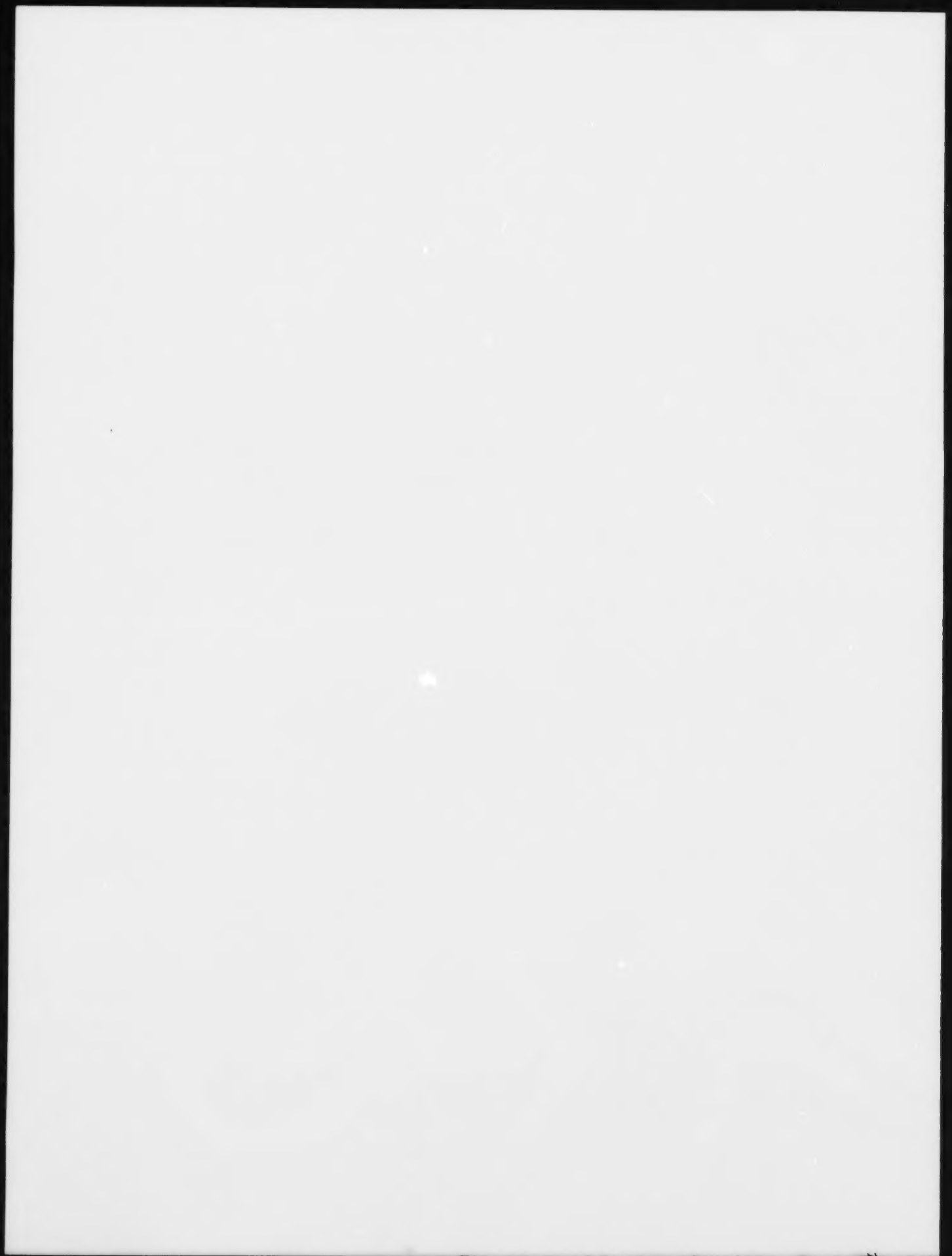
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THE IMPLICATIONS OF DRILLHOLE P59A ON COAL EXPLORATION IN THE STELLARTON BASIN¹

R. D. Naylor and W. D. Smith

Drillhole P59A was drilled by the Nova Scotia Department of Mines and Energy on the east side of the Stellarton Basin during the summer of 1987. The hole cored strata of the Thorburn and Coal Brook Members (Stellarton Group) comprising interbedded sandstone, mudrock, oil shale, minor coal from 5.5 - 1034.8 m and a significant coal seam from 1034.8 - 1041.2 m. The drillhole was terminated at a depth of 1042.7 m due to difficult drilling conditions.

The coal seam cored from 1034.8-1041.2 m consists of an upper and lower leaf separated by 3.12 m of coaly shale and coaly mudrock (Fig. 1). The upper leaf is 2.25 m thick with a total of 1.44 m having less than 30% ash (Fig. 1). Except for a 0.26 m thick section in the lower leaf, the remainder of the seam has an ash content in excess of 30%. This seam has been correlated with the Foord Seam (K. Gillis, personal communication, 1987) through projection of the seam from adjacent drillholes using bedding attitudes, correlation of downhole geophysical logs and interpretation of seismic profiles. However, on the basis of the stratigraphic succession recognized in the drill core, the authors favour correlation of the seam with the McLeod Seam. The McLeod Seam lies approximately 170 m stratigraphically above the Foord Seam.

A basinwide correlation of the

coals and oil shales of the upper Stellarton Group (see Fig. 2) established by Naylor et al. (1986, 1988) was used to correlate the stratigraphic sequence intersected in P59A. Figure 3 presents an east to west stratigraphic reconstruction which includes the strata intersected in drillhole P59A. The drillhole, which was collared at the approximate stratigraphic level of oil shale unit three, cored the entire sequence of oil shales and coals from oil shale unit four to the McLeod Seam. In P59A the number and thickness of sandstone bodies and the occurrence of rooted horizons below oil shales are substantially greater, relative to drillholes farther to the west. The oil shales intersected in P59A continue to split and thin toward the eastern basin margin.

Identification of the McLeod Seam in drillhole P59A extends the eastern limit of the seam by approximately 1000 m. Figures 4a and 4b illustrate the change in thickness and quality of the McLeod Seam over the east half of the Stellarton Basin. The total seam thickness isopach (Fig. 4a) shows that the seam pinches out toward the basin centre and thickens toward the southern and eastern basin margins. Figure 4b is an isopach map of the total interval thickness of coal with less than 30% ash within the McLeod Seam. This figure illustrates that although coal thickness is maintained in drillholes

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

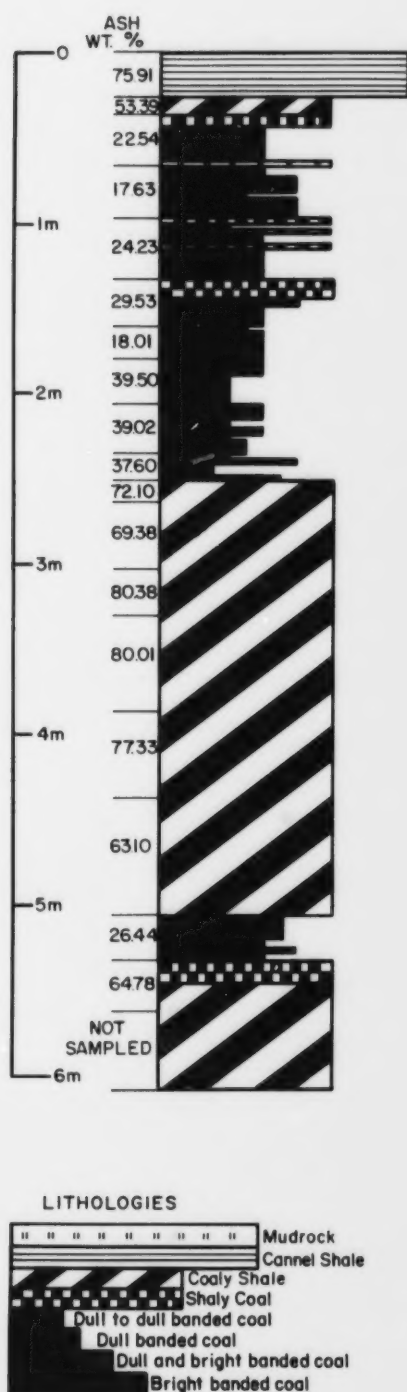


Figure 1. Seam profile and ash values of the McLeod Seam interval, drillhole P59A.

to the north (e.g. AP395) coal is of lesser quality in the northern part of the basin. It would appear, therefore, that the McLeod Seam is best developed to the south and east of drillholes AP401 and P59A. Further resource evaluation of the McLeod Seam should be concentrated in this area.

The sandstone sequences of the Coal Brook Member have been interpreted by Naylor et al. (1986) as lacustrine deltas which infilled central basin lakes where organic-rich muds, the precursors of oil shales, accumulated. During periods of delta abandonment, peat swamps occasionally formed on the delta plain resulting in formation of coals such as the McLeod Seam. The increased occurrence of sandstone sequences and rooted horizons, coupled with a thinning and splitting of the oil shales, suggests that a delta front-lower delta plain position was maintained for longer periods in this location compared to areas farther to the west. The absence of thick coal seams, other than the McLeod in drillhole P59A, suggests that transgression of lakes from the basin centre generally drowned the delta plains in the area of P59A before peat swamps became established. Farther to the east and higher in the section, significant peat swamps occasionally formed during periods of delta abandonment, as revealed by the development of the McBean and Sixfoot Seams of the Thorburn Member. The occurrence of undiscovered coal seams within the Coal Brook Member east of drillhole P59A, therefore, remains an interesting possibility worth further exploration.

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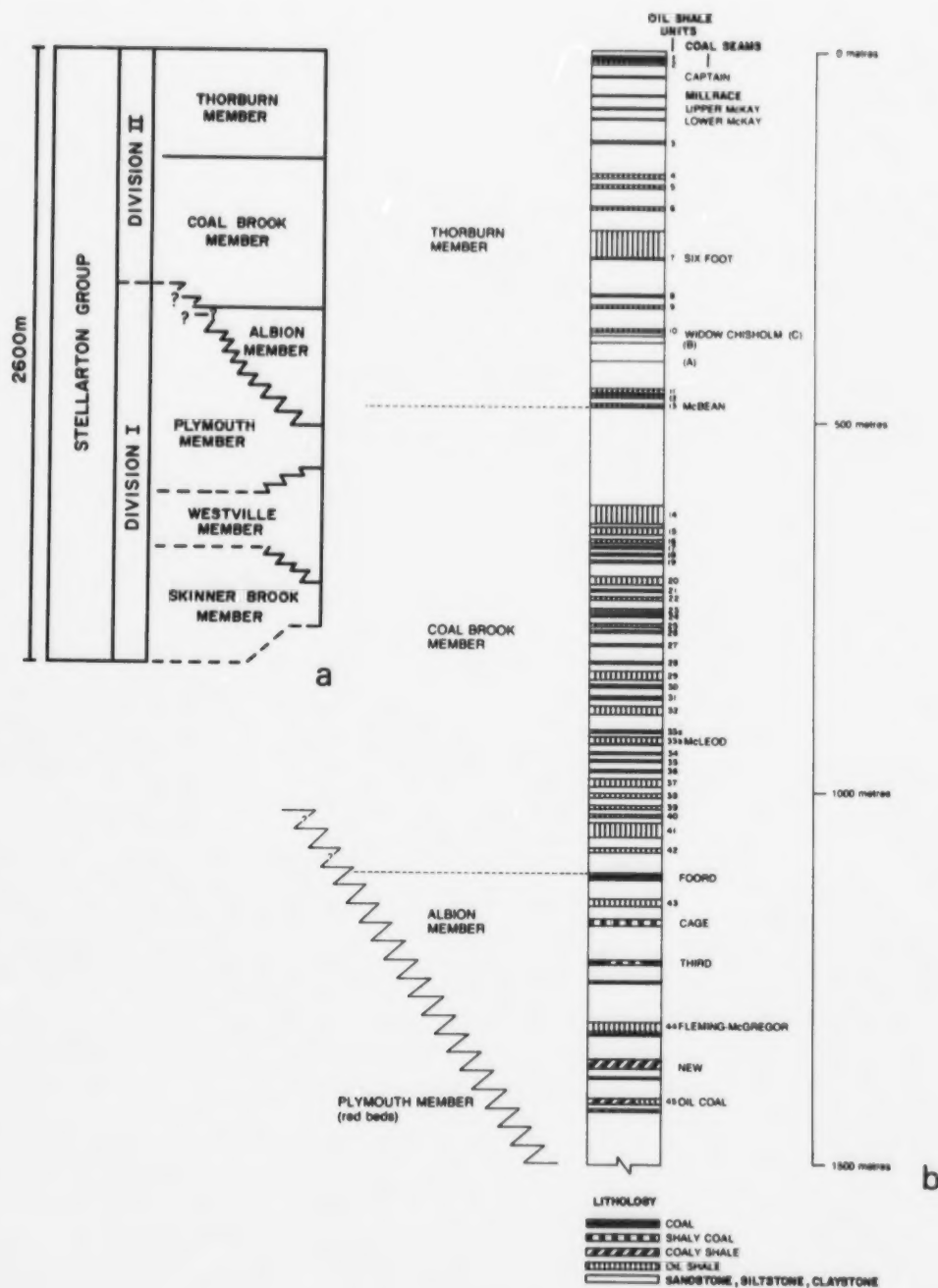
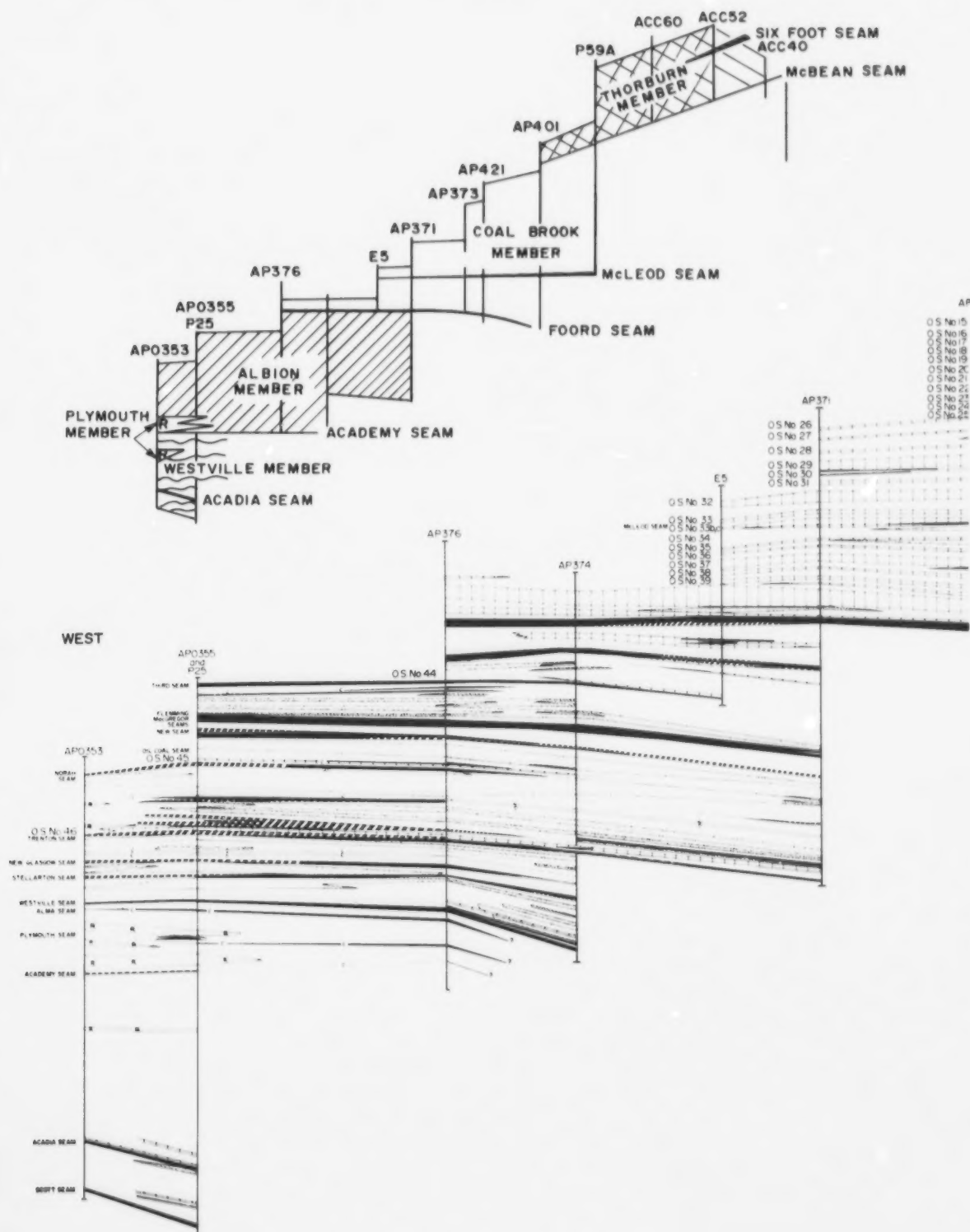


Figure 2. Stratigraphic column - east side of Stellarton Basin. Member names and boundaries after Bell, 1940.



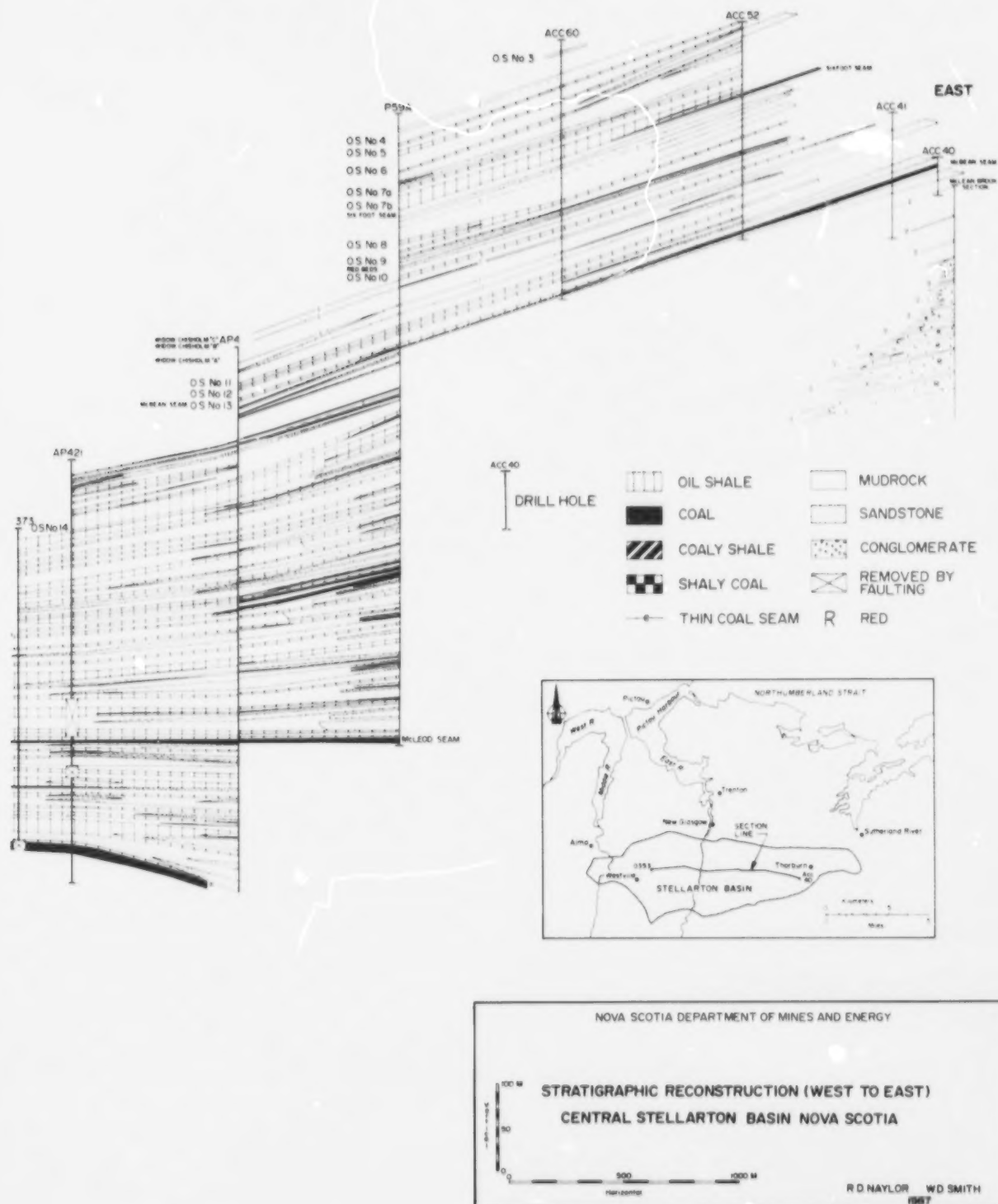


Figure 3. Stratigraphic reconstruction (west to east), Stellarton graben, Nova Scotia.

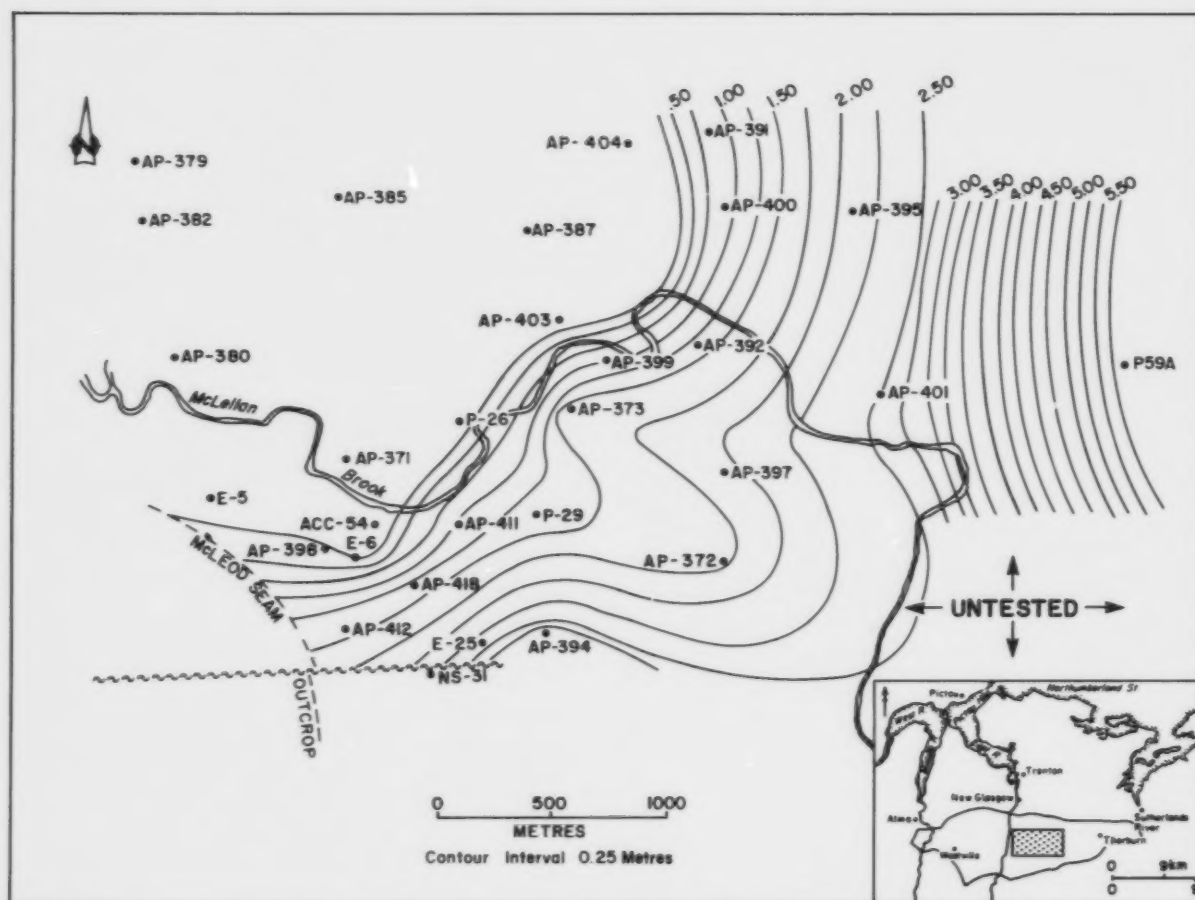


Figure 4(a). Isopach map of McLeod Seam illustrating total seam thickness.

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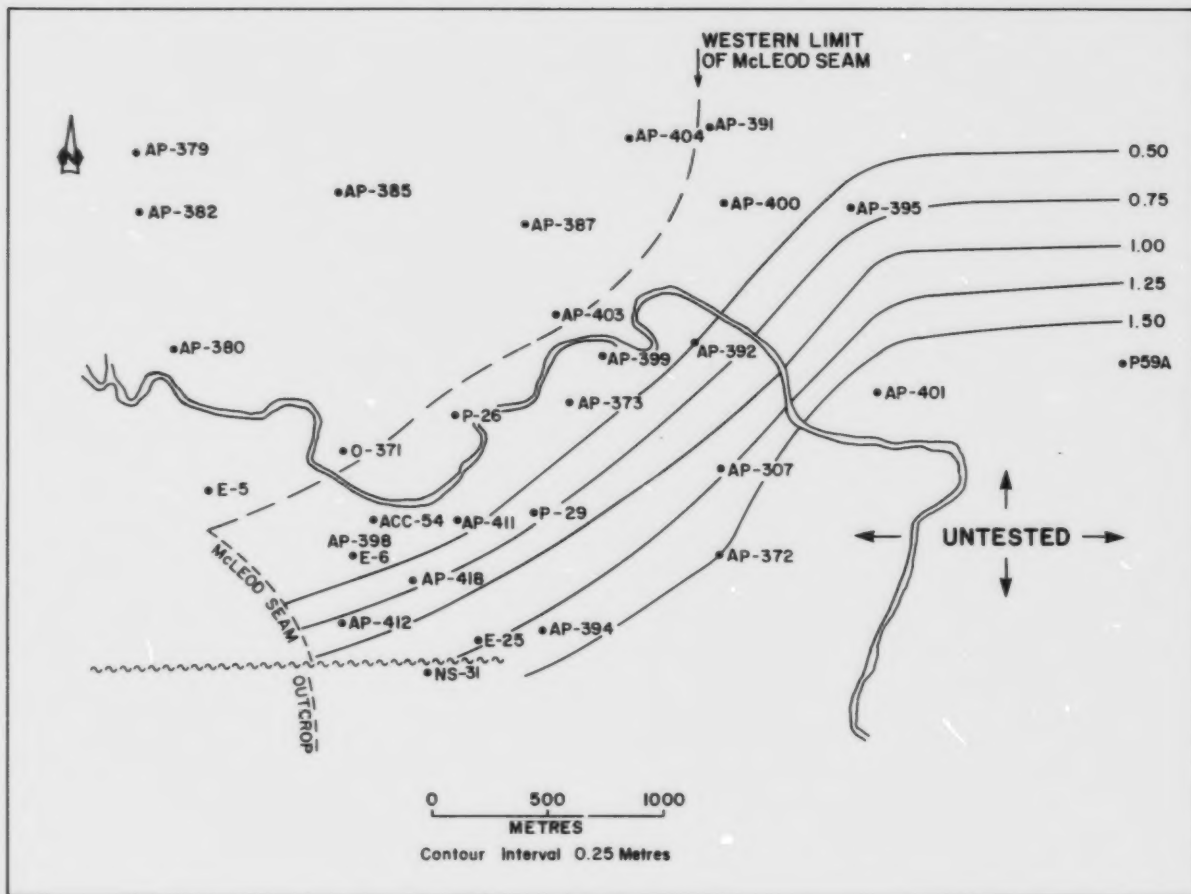


Figure 4(b). Isopach map of the total thickness of coal within the McLeod Seam which has less than 30% ash.

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REPORT ON INVESTIGATIONS OF OIL SHALE OCCURRENCES OF NOVA SCOTIA: A SUMMARY AND UPDATE¹

R. D. Naylor and W. D. Smith

Oil shale occurrences have been reported in strata which range in age from Middle Devonian to Late Permian in the Cape Breton, Northern Mainland and Annapolis Valley areas of Nova Scotia since the 1800s (Figs. 1 and 2). In

order to assess the potential of the Province's oil shale resources, investigation of their geology and composition is needed.

Investigation of these resources was initiated in 1985 in the Stellarton Basin, the Province's largest and best known occurrence. Project work continued in the Stellarton Basin in 1986 and work included the lesser known occurrences of Nova Scotia in 1987. This report is intended to summarize the lithology, mineralogy, geochemistry, organic petrography and yield information presented in earlier reports (Naylor et al., 1985, 1986a, 1986b, 1987a, 1987b, 1987c, 1988a, 1988b; Naylor and Smith, 1986a, 1986b, 1987; and Yeo et al., 1988) and to update the data presented in Naylor et al. (1987a).



Figure 1. Location of oil shale occurrences examined by the Nova Scotia oil shale project; 1 - Stellarton; 2 - McAdams Lake; 3 - Horton Bluff; 4 - Big Marsh; 5 - Port Hawkesbury; 6 - Port Malcolm; 7 - Whiteside; 8 - Joggins; 9 - Maccan - Styles Brook; 10 - Trenton Syncline; 11 - Sydney; 12 - Mabou.

MIDDLE DEVONIAN (EIFELIAN)

MCADAMS LAKE

Oil shale occurrences within strata of the McAdams Lake Formation were reported in the McAdams Lake area, Cape Breton County (Fig. 1), as early as 1891 (Neville, 1891). The occurrence was mined in the late 1800s and recently it has been investigated

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

AGE	PERIOD		STAGE		
	PALEOZOIC	CARBONIFEROUS SYSTEMS	PENNSYLVANIAN	Westphalian	
		MISSISSIPPIAN	Tournaisian		
	DEVONIAN				

Figure 2. Geological column showing the stratigraphic position of reported oil shale-bearing strata of Nova Scotia. Age determinations for the locations are: 1 - Dolby (1987); 2 - Dolby (1986a); 3 - Dolby (1986b); 4 - Bell (1940); 5 - Hacquebard and Donaldson (1969); 6 - Bell (1944); 7 - Hacquebard and Donaldson (1964); 8 - Hacquebard (1972); 9 - Shea and Wallace (1962); 10 - Bell (1960); 11 - Benson (1974); 12 - Boehner and Giles (1982); 13 - McGregor (1977).

by the Nova Scotia Department of Mines and Energy (Potter, 1977) through diamond-drilling, however, no oil shale was intersected in the holes (Potter, 1977). The authors examined 500 m of strata exposed along a roadcut near

McAdams Lake. The strata are exposed at the crest of a southwesterly-plunging anticline and comprise dark green-grey siltstone, sandstone and conglomerate with nine thin (7.5 - 60 cm thick) interbeds of dark grey to black laminated silty shale in the basal 100 m of the section. Rock-Eval pyrolysis of three of these shales shows them to be thermally mature, containing 2.5 - 18.5% organic carbon and producing hydrocarbon yields of 1-20 l per tonne. The hydrogen indices, derived from Rock-Eval data, also indicate that the organic component of the shales is derived from carbonaceous (humic) matter rather than algal remains.

EARLY MISSISSIPPIAN (TOURNAISIAN)

Exposures of Horton Group shale were examined at Horton Bluff, Kings County, and Big Marsh, Antigonish County (Fig. 1).

HORTON BLUFF

The lacustrine middle shale unit of the Middle Member (Horton Bluff Formation), exposed along the Avon River at Horton Bluff, is 180 m thick (Martel and Gibling, 1988) and contains shales which are typically dark grey, silty and micaceous. Rock-Eval pyrolysis of four samples shows the shales to be thermally mature, containing less than 1% organic carbon and yielding less than 5 l of hydrocarbons per tonne. The organic component of these shales is thought to be carbonaceous rather than bituminous (Ells, 1910) and our Rock-Eval data tend to support this conclusion. Oil shales have also been mentioned from a deep borehole near Hantsport by Ells (1910) who reported the occurrence of a 10-12 foot (3-3.5 m) thick bed. This occurrence may represent shale richer in organic matter than the shales exposed at Horton Bluff.

BIG MARSH

In the Antigonish Basin, near Big Marsh, a 65-130 m thick section of silicate-rich oil shale can be traced from the headwaters of Wallace Brook to St. Georges Bay (a distance of about 13 km) (Macauley and Ball, 1984). The oil shale is typically black, massive, has a low specific gravity, resists fracture and has a conchoidal fracture style. Rock-Eval pyrolysis results show that the oil shale contains between 1.5-12.0% thermally mature organic carbon and gives hydrocarbon yields of 2.0-60 l per tonne. The organic component of the Big Marsh oil shales is characterized chiefly by algal detritus with minor amounts of humic material and spore and algal bodies (Kalkreuth and Macauley, 1986; 1987).

The richest portion of this oil shale comprises a section 6 m thick which underlies an area of 8 km² (How, 1868). A 60 m deep shaft was driven circa 1865 to reach this 6 m thick portion of the oil shale section (Ells, 1909) and was the only attempt at establishing an oil shale industry in this area.

EARLY PENNSYLVANIAN (WESTPHALIAN A)

Exposures of the Riversdale Group reported to contain oil shales were examined at Port Malcolm, Whiteside and Port Hawkesbury, all in Richmond County (Fig. 1). At Port Malcolm and Whiteside, dark grey to black, pelecypod-bearing shales were sampled (3 samples). Rock-Eval pyrolysis results show that they are thermally mature, contain 3-5% organic carbon and give hydrocarbon yields of 2.5-6.0 l per tonne. At Port Hawkesbury, a thin (10 cm thick) black silty shale bed was sampled; analyses show that it is thermally overmature and that virtually no hydrocarbons are generated from its content of 4% organic carbon.

MIDDLE PENNSYLVANIAN (LATE WESTPHALIAN A - WESTPHALIAN C)

JOGGINS

Strata belonging to the lowermost Cumberland Group were examined in outcrop at Joggins within the Joggins-Chignecto coalfield of the Cumberland Basin, Cumberland County (Fig. 1). Twelve thin (10 cm thick or less) and one thick (up to 1.7 m thick) organic-rich beds were examined in the 330 m of section below the Forty Brine Seam. These organic-rich rocks are typically black, ostracod- and pelecypod-bearing, shaly to massive bituminous limestone and organic-rich limy claystone which overlie and underlie coal seams. Rock-Eval pyrolysis of nine Joggins samples shows that they are thermally immature to near-maturity, contain 1-14% organic carbon and produce hydrocarbon yields of 1-20 l per tonne. The organic component of the bituminous limestones is composed predominantly of detrital vitrinite with minor amounts of algal debris and filamentous algae (W. Kalkreuth, personal communication, 1986).

STYLES BROOK, MACCAN

Strata of the lower to middle Cumberland Group were examined in drill core from Styles Brook and Maccan, also within the Joggins-Chignecto coalfield of the Cumberland Basin (Fig. 1). In the 100 m of section above the Forty Brine Seam, 13 organic-rich shale units were identified. The equivalent of the lower organic-rich package of Joggins is a coarse-grained clastic unit and probably represents a lateral facies change (J. Calder, personal communication, 1987).

These upper organic-rich shales are locally associated with thin coals and they comprise silicate-rich dark grey to black shales and black pelecypod-bearing shales which are up to 2.3 m thick. Rock-Eval pyrolysis of 11 of these shales shows that they are

approaching thermal maturity, have an organic carbon content of 0.5-10.0% and give hydrocarbon yields of 0.1-20.0 l per tonne. The shales also have hydrogen indices typical of organic matter derived from terrestrial/humic sources.

LATE PENNSYLVANIAN TO PERMIAN (LATE WESTPHALIAN B/C TO STEPHANIAN)

Strata belonging to the Pictou Group and its equivalents were investigated in the Stellarton Basin, Trenton Syncline, Sydney Basin and at Mabou (Fig. 1).

STELLARTON BASIN

At least 45 silicate-rich oil shale units, averaging 5 m thick each, have been identified within the upper part of the Stellarton Group (Thorburn, Coal Brook and upper Albion Members) in the Stellarton Basin. Additional oil shale units are also known to exist within the lower part of the group in the lower Albion Member and in the Westville Member.

The richest type of oil shale, boghead shale, occurs as 0.15-1.85 m thick beds which form part of oil shale units 4, 5, 6 (Thorburn Member) and 45 (Albion Member). The boghead shales have an average organic carbon content of 19% which comprises mostly algal remains and which produces average hydrocarbon yields of 110 l per tonne. Boghead shale can be identified easily because of its tendency to fluoresce under a hand-held ultraviolet (UV) light.

The most extensive and thickest development of oil shale is contained within 500 m of strata which underlie an area of approximately 15 km² east of East River. Oil shale units 14 to 42, which are interbedded with claystone and minor siltstone and coal, make up 45% of this section and comprise sub-fissile alginite-bearing shale and

minor thin beds of massive, conchoidally fracturing cannel shale. The alginite-bearing shales have a low organic content (average of 5%) comprising algal debris with minor humics and giving hydrocarbon yields of 25 l per tonne or less. The cannel shales contain up to 40% organic carbon, comprising detrital humic matter with minor algal debris and giving hydrocarbon yields of 7-130 l per tonne (40 l/t average).

No oil shale development has occurred in the Stellarton area since 1930. Prior to this time short-lived attempts were concentrated on oil shale units 4, 22 and 45.

TRENTON SYNCLINE

In the Trenton Syncline, north of New Glasgow, oil shales have been identified in Smalls Brook and in two exploratory drillholes, P57 and P58, drilled for coal and oil shale by the Nova Scotia Department of Mines and Energy in 1986 (D'Orsay et al., 1986). The oil shales, which are associated with thin coal seams, are silicate-rich, dark grey to black and contain vitrainous coaly laminae, plant remains, pelecypods, ostracods and locally fecal pellets. Some of the oil shales are probably boghead shales as they fluoresce under a UV light in a manner similar to the boghead shales of the Stellarton Group.

Hole P57 intersected 29 oil shale beds ranging in thickness from 0.2-1.0 m (average 0.4 m thick). Twenty eight beds were encountered at a depth of 13-61 m, accounting for 21% of the interval thickness, and one oil shale bed was encountered at a depth of 95.40-95.90 m. Along Smalls Brook and in hole P58 only one oil shale bed was encountered; in hole P58 the oil shale bed was encountered at a depth of 447.53-447.64 m. Rock-Eval pyrolysis of 14 samples indicates that they are thermally mature (slightly), contain 4-16% organic carbon and give hydrocarbon

yields of 8.5-55.0 l per tonne. The organic component comprises a 3:1 admixture of algal and humic debris.

SYDNEY BASIN

Exposures of Morien Group strata (Sydney Mines Formation) were examined at Dominion and Great Bras d'Or. At Dominion petroliferous and carbonate-rich silty shales were sampled above the Emery and Phalen Seams. At Great Bras d'Or a 40 cm thick petroliferous and pelecypod-bearing limestone was sampled above the Backpit Seam. Rock-Eval pyrolysis of these samples shows that they all contain less than 4% organic carbon, are thermally mature and give hydrocarbon yields of less than 7.5 l per tonne. The hydrogen indices suggest that the organic matter of the shales is derived from predominantly humic material and that the organic matter of the petroliferous limestone comprises a mixture of material derived from humic and liptinitic sources.

Black shales exposed at Glace Bay and Victoria Mines, however, are reported to have organic carbon contents of 10-40% and give hydrocarbon yields of 40-150 l per tonne (M. Gibling and W. Kalkreuth, personal communication, 1987). Organic petrology of six samples from these locations shows that five of them are spore-rich and one is rich in humic matter (vitrinite).

MABOU

Strata of the coal-bearing Inverness Formation, exposed at Coal Mine Point 19 km northwest of Mabou, contain 1-2 m thick beds of pelecypod-bearing and silicate-rich black shale. Rock-Eval pyrolysis of one sample gave an organic carbon content of 10% and a hydrocarbon yield of 20 l per tonne. The data also show that the organic matter is near the onset of thermal maturation and that it has a hydrogen

index consistent with derivation from a humic source. Analysis of three black shale samples from the same area by M. Gibling and W. Kalkreuth (personal communication, 1987) showed similar results with contents of 2.5-13% organic carbon, hydrocarbon yields of 2.5-37.5 l per tonne and an organic component comprising mainly humic material.

CONCLUSIONS

One accepted definition of an oil shale is a compact, fine-grained rock comprising mineral matter and organic carbon which yields more than 25 l of hydrocarbons per tonne upon retorting (Yen and Chilingarian, 1976; Tissot and Welte, 1984). As a result, some of the occurrences discussed above, those occurrences which are merely organic-rich shales, have been improperly reported as oil shale by earlier workers.

The principal oil shale resources of the Province occur in the Stellarton Basin, Trenton Syncline and Antigonish Basin. The Cumberland Basin and Sydney Basin may also contain significant oil shale resources. The resource is considered to have yields too low for immediate use but may be of importance to our future energy reserves.

A scheme for indirect uses of the oil shales may, however, enhance the economics of their development. One such example would be to use the oil shales both for their organic content, to generate electricity or petroleum, and for their ash, to produce industrial materials (such as bricks or cement), as was successfully carried out in Germany (Macauley and Ball, 1982). Another example is co-combustion of oil shale with high sulphur coal to reduce sulphur emissions during thermal power generation. The oil shales of New Brunswick are currently attracting attention for the latter purpose (Macauley et al., 1985) because of

their energy content and their carbonate-rich character.

In Nova Scotia the silicate-rich oil shales of Stellarton Basin, Trenton Syncline and Big Marsh may prove useful as a raw material for brick making or as a cement mix following electric power/petroleum generation. This possibility for the Stellarton oil shales received limited attention in 1958 but work did not proceed beyond a preliminary stage of investigation (Haw, 1958).

The carbonate-rich, bituminous limestones/oil shales of the Cumberland and Sydney Basins may make a useful additive to our coal-fired electric generators for the purpose of reducing sulphur emissions. The use of these limestones may become increasingly attractive as demands for reduced sulphur emissions increase, especially in light of the fact that the coals of the Sydney coalfield, the largest reserve in eastern Canada, contain relatively high levels of sulphur.

Finally, the occurrence of oil shales and organic-rich shales in this Province may have significant implications for hydrocarbon exploration. The presence of hydrocarbon shows and accumulations in the Maritimes (Stellarton Basin, Hants County, Lake Ainslie area, Moncton Basin) in age equivalent strata to some of these oil shales/organic-rich shales suggests that they may have acted as a petroleum source rock, a potential that is worthy of investigation.

Work on the oil shale resources of Nova Scotia will continue during the next fiscal year. A report detailing the results presented here is in preparation.

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MINERAL EXPLORATION MONITORING ACTIVITIES

J. M. McMullin and P. D. McCulloch

INTRODUCTION

Monitoring of mineral exploration activity in Nova Scotia is the responsibility of the Resource Geology Section of the Mineral Development Division. Staff assigned to this program include a regional geologist and a project geologist based in the regional office at Stellarton, Pictou County.

The monitoring process covers all exploration activities in the Province and includes regular visits to company offices and exploration sites, liaison with industry personnel and reviews of current assessment reports and other material submitted by industry. Direct liaison with industry allows the Department to maintain an awareness of current exploration activities throughout the Province. Problems and difficulties which may need to be addressed by the Department are identified and assistance or advice is provided if necessary. A statistical survey of exploration expenditures is compiled annually to obtain data on costs related to the various sectors of the mineral industry in the Province.

In addition, all drill core generated in the Province by the various mining exploration companies is recorded as part of the monitoring process. This core may be recovered for the Drill Core Library in Stellarton when no longer required by the companies.

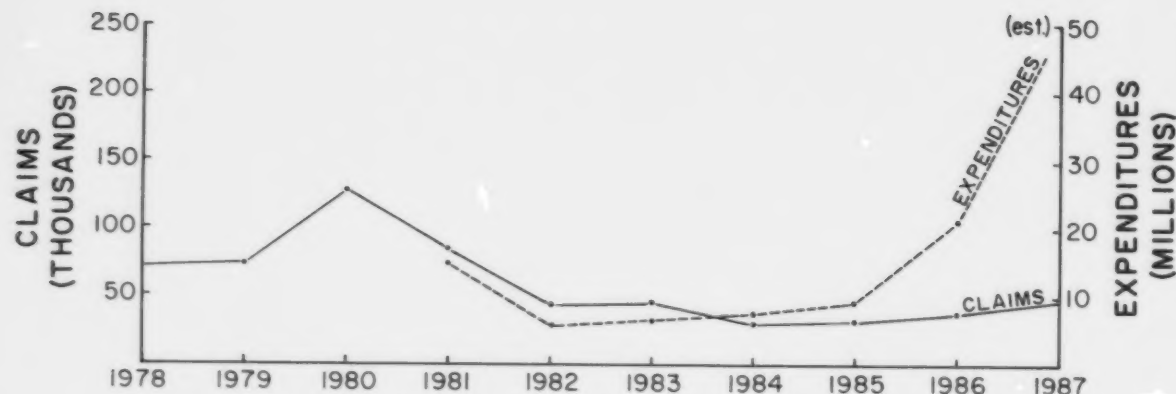
MINERAL EXPLORATION ACTIVITY IN 1987

Mineral exploration activity continued to gain momentum during 1987 with a substantial increase over 1986

and eclipsing the record levels of 1980-81. A preliminary estimate in excess of \$50 million is predicted for the cost of exploration work conducted in the Province during 1987 for all minerals except petroleum, roughly two and a half times the \$20 million spent in 1986 and more than five times the \$9 million spent in 1985 (Fig. 1). Exploration for gold accounted for the large increase in expenditures as companies continued to focus on precious metal exploration. The record expenditure levels in 1987 can be partly attributed to the advanced stage of several exploration projects for gold that include underground exploration and development work. The continued stability in the current price of gold in relation to other mineral commodities, primarily base metals, and the continuing availability of flow-through financing have played a major role in the current level of gold exploration in the Province. In addition, the success of several junior companies in delineating significant tonnages of ore-grade reserves has also resulted in establishing credibility in the historic gold mining camps in Nova Scotia.

Approximately 1350 diamond-drill holes totalling 205 000 m were completed in 1987 for mineral exploration and development.

The number of general claims staked in 1987 increased by 26% over the previous year to 46 482 and represents a 67% increase over the two year period since 1985 (Table 1). The number of claims for salt and potash continued to drop in 1987 but a significant increase was recorded in the number of claims for coal. A total



CLAIMS ISSUED AND EXPENDITURE LEVELS (ANNUAL)

- (1) All commodities excluding petroleum.
(2) Statistics not available for 1978-80.

Figure 1. Plot of claims issued and expenditure levels, 1978-1987.

of 48,355 claims for all commodities were in effect at the end of 1987 represented by 1783 exploration, development and special licences and covering an area of just over 1.9 million acres (approximately 7700 km²), roughly 14% of the total area of the Province. In addition, 12,500 claims (1800 km²) remained closed to exploration as a result of the uranium moratorium.

More than 225 companies and individuals held exploration interests (licence or options) in the Province in 1987 including 24 major, 28 junior and 25 private companies (Tables 2 and 3). In addition, several mining lease holders carried out exploration on their leases or on unclaimed ground where these commodities did not require licences (e.g. limestone, gypsum). Organizations actively engaged in exploration and development work during 1987 included 14 major, 20 junior and approximately 18 private companies and a number of individuals.

Several companies not previously active in the Province completed exploration programs during 1987. These include Placer Development Limited, Teck Corporation, Gordex Minerals Limited, Scotia Prime Resources Limited and several Nova Scotia based private companies. Scotia Prime Resources Limited opened an exploration office in Halifax during the year and Suncor Incorporated closed its office in New Glasgow. Durham Resources Incorporated changed its name in 1987 to Landmark Corporation and sold its mining interests to majority-owned Dominion Explorers Incorporated. Novacan Mining Resources (1985) Limited changed its name to Novagold Resources Incorporated.

MINING EXPLORATION

GOLD

Exploration for metallic minerals in the province continued to focus on gold during 1987, concurrent with a

Table 1. Record of exploration information, 1978-1987.

Year	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
Total exploration expenditures	MA	MA	MA	14,607,662	5,552,675	6,500,000*	7,300,000*	9,000,000*	20,000,000*	50,000,000*
Total licences issued - all categories	2,393	1,841	2,559	1,952	1,298	1,350	1,039	1,025	1,347	1,733
Current claims	38,597	40,497	88,703	68,863	39,626	40,630	26,627	27,809#	36,714#	46,482#
Coal	MA	MA	MA	4,880	3,072	4,565	3,584	3,584	482	1,681
Salt and Potash	1,148	2,256	13,505	5,225	1,065	505	1,257	830	306	192
Uranium	31,978	30,920	25,483	6,225	MA	(12,500) (closure)	(12,500) (closure)	(12,500) (closure)	(12,500) (closure)	(12,500) (closure)
Total (excluding closures)	71,723	73,673	127,691	85,193	43,763	45,700	31,468	32,223	37,502	48,355
Total area held under licence (acres) (no adjustment made for multiple licences on the same ground)	2,868,920	2,946,920	5,107,640	3,407,720	1,750,520	1,828,000	1,258,720	1,334,560	1,468,568	1,836,480
Assessment work reported for licence renewals (\$)	5,900,000	4,700,000	7,564,000	8,441,270	4,107,273	4,200,210	2,625,666	2,389,351	9,954,014	26,713,524
Number of assessment reports submitted	132	126	140	157	124	188	140	108	154	270

* preliminary figures

includes tailings and development licence claims

MA = not available

similar emphasis on precious metals exploration and development projects in other provinces. A significant increase in gold exploration activity was recorded in 1987 over 1986 with expenditures more than doubling over the previous year. A number of new exploration programs were initiated during the year and several large-scale exploration and development programs continued from 1986. Most of the exploration programs for gold were carried out by the junior companies although an increase in exploration activity was recorded by the major companies in 1987. The continued interest in gold exploration in the Province suggests that the current level of activity should extend into 1988.

Exploration for gold was concentrated primarily in the historic gold districts throughout southern mainland Nova Scotia where gold-bearing quartz veins occur in Cambro-Ordovician metasedimentary rocks of the Meguma Group. The gold occurs primarily in stratiform quartz veins along the north and south limbs of northeast-trending anticlinal folds of the Goldenville Formation. Most of the production in the gold districts took place during the period 1860-1915 on over 40 significant properties with the largest production (210,150 oz.) recorded from the Goldenville property in Guysborough County.

An increasing number of new and continuing exploration programs were undertaken by the junior companies during 1987 with the majority of work concentrated in Halifax and Guysborough Counties (Fig. 2). The work included surface exploration consisting of geochemical and geophysical surveys, geological mapping, trenching and diamond-drilling, and underground exploration consisting primarily of diamond-drilling and bulk sampling.

Seabright Resources Incorporated continued a detailed surface and

underground exploration program on both the Forest Hill property in Guysborough County and the Beaver Dam property in Halifax County. The company also initiated a large-scale surface and underground exploration program on the recently acquired Caribou gold property in Halifax County and continued surface exploration programs on several other properties.

Seabright acquired an option on the Forest Hill gold property in 1981 and since that time has completed a large-scale surface and underground exploration program including extensive diamond-drilling, shaft sinking and bulk sampling. The company continued underground exploration and development work on the main zone during 1987 and completed surface diamond-drilling on a zone east of the shaft. A development ramp was also started on the east zone to facilitate an underground drilling and bulk sampling program. Reserve estimates at the end of the year were placed at 384,000 tons of proven and probable ore grading 0.48 oz./ton.

Seabright optioned the Beaver Dam gold property from Acadia Mineral Ventures Limited in 1985 and to date has completed a large-scale surface and underground exploration program consisting primarily of diamond-drilling and bulk sampling. A decline was started on the property in mid 1986 to facilitate these activities. This work continued during 1987 to evaluate the ore reserves outlined in the surface drilling program. Proven ore reserves stand at 1.1 million tons grading 0.27 oz./ton with additional inferred reserves estimated at 1.9 million tons of similar grade.

The Caribou gold property was acquired by Seabright from John Logan Enterprises Limited in 1986. The company completed 2 diamond-drill holes totalling 200 m early in 1987 and began a large-scale surface exploration program consisting of soil geochemistry, ground geophysics and

diamond-drilling later in the year. The Holman shaft was also de-watered to facilitate a detailed underground evaluation of the old workings which included geological mapping, extensive sampling and diamond-drilling. This work is to be continued in 1988.

Seabright also continued a large surface exploration program on the Moose River gold property in Halifax County. The company carried out initial work on the property in 1985 and in 1986 completed detailed ground geophysical surveys and diamond-drilling. The drilling program continued in 1987 with over 160 holes completed by the end of the year.

A large-scale regional exploration program for gold was carried out by Seabright in several areas throughout Halifax and Guysborough Counties. Work was undertaken to examine the strike extension of several anticlinal structures that host a number of significant gold deposits. Follow-up work, consisting primarily of geochemical surveys and diamond-drilling, was completed on several properties as a result of the regional exploration program.

Coxheath Gold Holdings Limited continued a detailed surface and underground exploration program on the Tangier gold property in Halifax County. The company acquired the property in 1986 and began a detailed surface exploration program consisting primarily of diamond-drilling. Work continued in 1987 with the addition of an underground bulk sampling and diamond-drilling program along with an expanded surface drilling program. A decline was collared early in the year and the underground bulk sampling and diamond-drilling program was carried out in two phases, the second to be continued in 1988. Drilling to date has outlined inferred ore reserves in the probable and possible categories of 1.9 million tons grading 0.27 oz./ton.

A surface exploration program was also completed by Coxheath on the Gold River gold property in Lunenburg County and included a diamond-drilling program totalling approximately 700 m. The company also completed airborne geophysical surveys over several of its properties throughout the Province.

Acadia Mineral Ventures Limited continued a large-scale surface exploration program on the Mooseland gold property in Halifax County. The company optioned the property from Tri-Explorations Limited in late 1986 and began a detailed exploration program including ground geophysics and diamond-drilling in December. The drilling program continued throughout 1987 with more than 100 drillholes completed by year end. Drilling on the 'west zone' in the vicinity of the old workings has outlined 645,000 tons of inferred ore reserves in the probable and possible categories grading 0.24 oz./ton. Drilling continues on the newly discovered 'east zone', which is the faulted strike extension of the 'west zone'.

Additional work was completed by Acadia on the Renfrew gold property in Hants County and included ground geophysics and diamond-drilling totalling 3300 m. The company also carried out exploration programs consisting primarily of ground geophysical surveys and diamond-drilling on the Mount Uniacke gold property in Hants County, the Wine Harbour gold property in Guysborough County and the Carleton gold property in Yarmouth County.

Novagold Resources Incorporated (formerly Novacan Mining Resources Limited) continued a large-scale surface exploration program on their Fifteen Mile Stream gold property in Halifax County. The company acquired the property in 1984 and began a detailed exploration program in 1986 consisting of ground geophysical surveys, trenching and diamond-drilling

Table 2. Major companies with interests in mineral exploration in Nova Scotia.

Company Name	1985	1986	1987	1987 Office Location in Nova Scotia
BP Resources Canada Limited	x	x	x	Halifax
Canada Cement Lafarge Limited	x	x	x	Brookfield
Canada Offshore Resources Exploration Limited (through SCOMINEX*)	x			
Canamax Resources Incorporated	-	-	-	
Conwest Exploration Company Limited	-	-	-	
Domtar Incorporated	-	x	x	Windsor
Eldorado Resources Limited (ground alienation)	-	-	-	
Esso Minerals Canada Limited	x	-	-	
Falconbridge Limited (formerly Kid Creek Mines Limited)	x	x	x	
Fundy Gypsum Company Limited	-	x	x	Windsor
Georgia Pacific Corporation	-	x	-	River Denys
Granges Exploration Limited	x	x	x	
Hecla Mining Company of Canada	-	-	x	
Husky Oil Operations Limited (through SCOMINEX*)	x	x	x	
Inco Limited (manager of SCOMINEX*)	x	x	x	Halifax
International Limestone Industries Limited (Scotia Limestone Limited)	x	x	x	Sydney
Interuranium Canada Limited - formerly Saarberg Interplan (ground alienation)	-	-	-	
Kennco Exploration Canada Limited	x	-	-	
Kerr Addison Mines Limited	x	-	-	
Landmark Corporation (formerly Durham Resources)	x	-	x	
Mosher Limestone	x	x	-	Upper Musquodoboit
National Gypsum (Canada) Limited	-	x	x	Milford Station
Noranda Exploration Company Limited	x	x	x	
Nova Construction Company	x	x	-	Antigonish
Novacorp Engineering Services Limited	x	-	-	
Nova Scotia Sand and Gravel Limited (division of L. E. Shaw Limited)	x	x	x	Halifax
Placer Development Limited	-	-	x	
Republic Gypsum Company	x	x	-	
Rio Algom Exploration Limited	x	x	-	
Rio Algom Limited	-	-	-	
Suncor Incorporated	x	x	-	New Glasgow
Teck Corporation	-	-	x	
Timminco Limited (Chromasco)	x	x	-	
U.S. Borax & Chemical Corporation (Pacific Coast Mines)	x	x	-	

x indicates work performed

- inactive

(if blank, company not operational)

*Scotian Mineral Exploration Venture

Table 3. Junior and private exploration companies operating in Nova Scotia.

Company Name	1985	1986	1987	1987 Office Location
Acadian Gold Mines Limited	x	-	-	
Acadia Mineral Ventures Limited	x	x	x	Truro
Arisaig Exploration Limited			x	
Atlantic Goldfields Incorporated			x	Halifax
Aurion Minerals Limited			x	Halifax
Bear Pass Resources Corporation (now a subsidiary of Tournigan Mining Exploration Limited)	x	x	-	
Bigstone Minerals Limited	x	-	-	
Bluestack Resources Limited	-	x	x	
Brador Minerals Incorporated			-	
Carbontec Industries Limited		x	x	Halifax
Carrick Gold Resources Limited			x	
Cobequid Resources Limited	x	x	x	Halifax
Coxheath Gold Holdings Limited	x	x	x	Bedford
Cumbercoal Limited	x	-	-	
Cuvier Mines Incorporated	x	-	-	
Explorer Industries Limited	-	-	-	
Fenorex Mineral Investigations Limited			x	Sydney River
Four Seasons Resources Limited	-	x	x	
Gedoro Mining Limited		x	x	Halifax
Gold Brook Developments Limited	x	x	x	Margaree
Golden Shore Explorations			-	Dartmouth
Goldenville Explorations Limited (now a subsidiary of Northumberland Mines Limited)	x	-		
Gordex Minerals Limited	-	-	x	
Greenstrike Gold Corporation	-	x	x	
Gusto Resources Limited			x	Halifax
Hathor Resources Incorporated			-	
Imperial Platinum Corporation		-	-	
Jascan Resources Incorporated	x	x	x	Halifax
Kelrock Limited	x	x	x	Antigonish
Little Lake Gold Mines Limited		-	-	Dartmouth
Lodestone Limited	-	x	x	Halifax
Lodge Resources Incorporated		-	x	Dartmouth
Lotus Resources Limited			-	Dartmouth
Magstone Development Limited	-	-	-	
Megaflo Mines and Energy Corporation	x	x	-	
Meguma Gold Corporation Limited*	x			
MER Resources Incorporated	x	x	x	Dartmouth
MEX Exploration Limited	x	x	x	Truro
Midas Minerals Incorporated			-	
Middle Belt Mines Limited	x	x	-	
Mid-North Resources Limited	x	-	-	
Mono Gold Mines Incorporated		x	-	
Northumberland Mines Limited	x	x	x	
Novagold Resources Incorporated (formerly Novacan Mining Resources (1985) Limited)	-	x	x	Halifax
Novamin Resources Incorporated (formerly Sulpetro Minerals Limited)	-	-	-	
Oldham Resources Limited	x	x	x	Dartmouth
Onitap Resources Incorporated	x	-	x	
Outland Resources Corporation	x	x	-	
Pan East Resources Incorporated	x	x		
Petromet Resources Limited	-	x	x	
Rainbow Resources Limited		-	x	Dartmouth
Scotia Prime Resources Limited			x	Halifax
Scotsville Mineral Resources Limited	x	-		
Seabright Resources Incorporated	x	x	x	Sackville
Seascope Consultants Limited		-	x	Halifax
Skyerock Minerals Limited			x	Antigonish
The Potter Mine (Nova Scotia) Limited		x	x	
Torene Gold Exploration Limited	-	x	x	Dartmouth
Tournigan Mining Exploration Limited	x	x	x	
Trafalgar Resource Investments Limited	-	-		
Tri-Explorations Limited	x	x	x	Dartmouth
Victoria County Explorations Incorporated	x	-	-	
Victoria Resource Corporation	x	x	-	
W. Bruce Dunlop Limited	x	x	x	
Web Exploration Services Limited		-	x	
Western Land Service Company Limited	-	x	-	
Wilco Mining Company Limited	-	x	x	

x indicates work performed

- inactive

(if blank, company not operational)

* now Coxheath Gold Holdings Limited

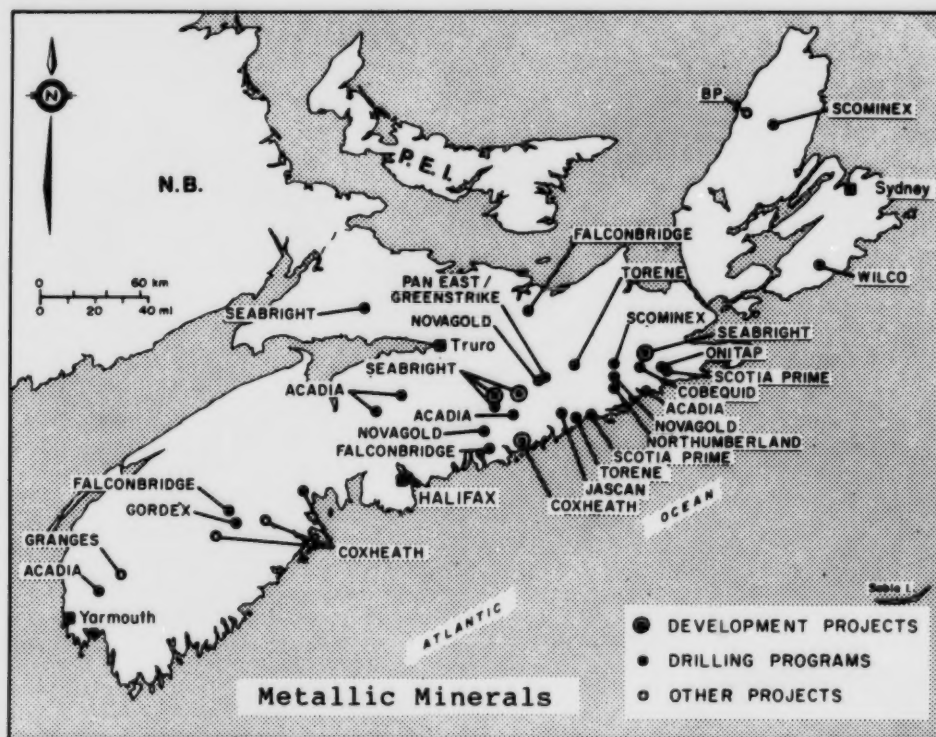


Figure 2. Location of principal exploration and development projects in Nova Scotia, 1987 (gold and base metals).

The drilling program resumed in August 1987 with over 70 holes completed by the end of December. Novagold also began a program of surface stripping and bulk sampling late in 1987 with plans to extract 20 000 tons of surface material from two surface cuts for processing at the Seabright Resources Incorporated mill at Gays River.

Novagold acquired the Lake Charlotte gold property in Halifax County from Middle Belt Mines Limited and began work, consisting primarily of ground geophysical surveys and diamond-drilling, on the property in September 1987. Exploration programs consisting of soil geochemistry, ground geophysics and diamond-drilling were also completed by Novagold at Cranberry Lakes, 8 km north of Sherbrooke in Guysborough County and at East Lake, 4 km southwest of the Fifteen Mile Stream gold property.

Through option agreements with Pan East Resources Incorporated, Greenstrike Gold Corporation and Petromet Resources Limited continued a large-scale diamond-drilling program on the Fifteen Mile Stream gold property in the immediate vicinity of the old workings. Drilling was undertaken in two phases under the direction of MPH Consulting Limited with a total of 12 000 m completed during the year.

Torene Gold Exploration Limited continued a detailed surface exploration program on the Harrigan Cove gold property 16 km east of Sheet Harbour, Halifax County. The company initiated diamond-drilling on the property in the fall of 1986 and completed ground geophysics and additional drilling totalling 6400 m during 1987. Torene also carried out soil geochemistry and diamond-drilling totalling 670 m on a property in the vicinity of Mitchell Brook, 7 km

southwest of Lower Caledonia in Guysborough County.

Inco Limited completed a detailed surface and underground exploration program on the Cochrane Hill gold property in Guysborough County early in 1987. The company acquired an option on the property from Northumberland Mines Limited in 1984, on behalf of the Scotian Mineral Exploration Venture group (SCOMINEX). A program of surface and underground diamond-drilling and underground bulk sampling began in late 1986 and was completed at the end of February 1987. Bulk samples were processed at the Northumberland mill facilities located on site.

Falconbridge Limited completed ground geophysics and diamond-drilling totalling 1000 m on the Brookfield gold property in Lunenburg County. The company recently optioned the property from Tri-Explorations Limited. Reconnaissance exploration for gold was also undertaken by Falconbridge on several other properties in the Meguma Group.

Several other gold exploration programs in the Meguma Group were completed or were still in progress at the end of 1987. Onitap Resources Incorporated, in an option with Petromet Resources Limited and Greenstrike Gold Corporation, continued a detailed diamond-drilling program on the Upper Seal Harbour gold property in Guysborough County completing just under 13 000 m by the end of 1987. Northumberland Mines Limited also continued an extensive diamond-drilling program on the Goldenville gold property in Guysborough County. Drilling was undertaken in two phases with the completion of just over 14 000 m by the end of 1987. Cobequid Resources Limited completed ground geophysics and diamond-drilling on the Highland property at Country Harbour, Guysborough County in 1987. Seabright Resources Incorporated currently has an option on the property. Jascan

Resources Incorporated completed a detailed diamond-drilling program on the Salmon River gold property in Halifax County. Drilling was carried out in two phases with the completion of over 40 holes totalling 6400 m. Jascan acquired a 50% interest in this property from Novamin Resources Incorporated as a result of work done in 1987.

Gordex Minerals Limited optioned the Molega gold property in Lunenburg County and began a large-scale exploration program in 1987. Work included soil geochemistry, ground geophysics and diamond-drilling under the direction of Derry, Mitchener, Booth & Wahl Consulting Limited. Scotia Prime Resources Limited acquired the Lower Seal Harbour gold property in Guysborough County and completed geochemical surveys and diamond-drilling totalling 5000 m during the fall. The company carried out a similar program on the Ecum Secum gold property in Halifax County late in 1987, completing just over 2300 m of drilling.

Exploration for gold was also carried out in the Cambrian and Hadrynian volcano-sedimentary rocks in other areas of the Province including the Cape Breton Highlands, the Antigonish Highlands, the Cobequid Uplands and southeastern Cape Breton Island. The gold potential of these areas has generally been ignored in the past but the recent success of gold exploration in similar environments in other areas, particularly southern Newfoundland, has focused some attention outside of the Meguma Group.

Inco Limited, on behalf of the Scotian Mineral Exploration Ventures group (SCOMINEX), continued a detailed evaluation of the Early Hadrynian basement complex of the Cape Breton Highlands. The company completed reconnaissance work in the Cape Breton Highlands during 1985-86 and began detailed follow-up in several areas in

1987. Detailed geochemical and geophysical surveys, trenching and diamond-drilling were concentrated in the MacMillan Flowage area approximately 25 km southeast of Cheticamp, Inverness County. Inco also carried out an airborne geophysical survey over the Big Pond area along the northern limits of the Fourchu Group in southeastern Cape Breton Island.

BP Resources Canada Limited completed additional follow-up work consisting primarily of trenching on a property in the Faribault Brook area, 6 km east of Cheticamp in Inverness County. Noranda Exploration Company Limited also continued a small exploration program in the Whycocomagh area, Inverness County. In other areas, Torene Gold Exploration Limited carried out an airborne geophysical survey in the Browns Mountain area of the Antigonish Highlands and Seabright Resources Incorporated completed a small diamond-drilling program near Farmington, Cumberland County. Coxheath Gold Holdings Limited carried out an airborne geophysical survey over the Coxheath property in the Boisdale Hills, approximately 15 km west of Sydney.

In addition to the above exploration programs, several small-scale exploration projects were carried out for gold by various companies and individuals throughout the Province (Tables 2 and 3). This work consisted primarily of reconnaissance soil geochemical surveys, prospecting and lithological sampling.

BASE METALS

Exploration for base metals continued to show little improvement over the past year due primarily to the lower price for tin and, until recently, consistently low prices for the traditional base metals Cu, Pb and Zn. As a result, only small-scale exploration programs for tin were

carried out in 1987 and only those base metal properties with potential precious metal association received attention.

Falconbridge Limited completed a small exploration program for tungsten in the Ship Harbour area, Halifax County, consisting of ground geophysics and diamond-drilling totalling 450 m. The company also carried out a small diamond-drilling program on the Kirkmount base metal property, approximately 9 km southeast of Stellarton, Pictou County. Granges Exploration Limited completed ground geophysical surveys on a tin property in the Solomon Lake area, Yarmouth County.

Wilco Mining Company Limited continued a detailed diamond-drilling program for base metals on the Stirling property in southeastern Cape Breton Island completing just over 5000 m during 1987. Coxheath Gold Holdings Limited carried out an airborne geophysical survey near Oceanview, approximately 20 km west of Louisbourg in Cape Breton County. The company has maintained ground holdings in the area to assess several significant base metal showings occurring in the Fourchu Group volcanics. Durham Resources Incorporated completed additional diamond-drilling totalling 1000 m on the West Gore antimony property in Hants County.

INDUSTRIAL MINERALS

Exploration for non-metallic minerals is undertaken primarily by industrial mineral producers with established mining operations in the Province (Fig. 3). A large proportion of the exploration activity for industrial minerals is the direct result of the ongoing development of limestone and gypsum resources and growing markets have resulted in a gradual increase in recent years to

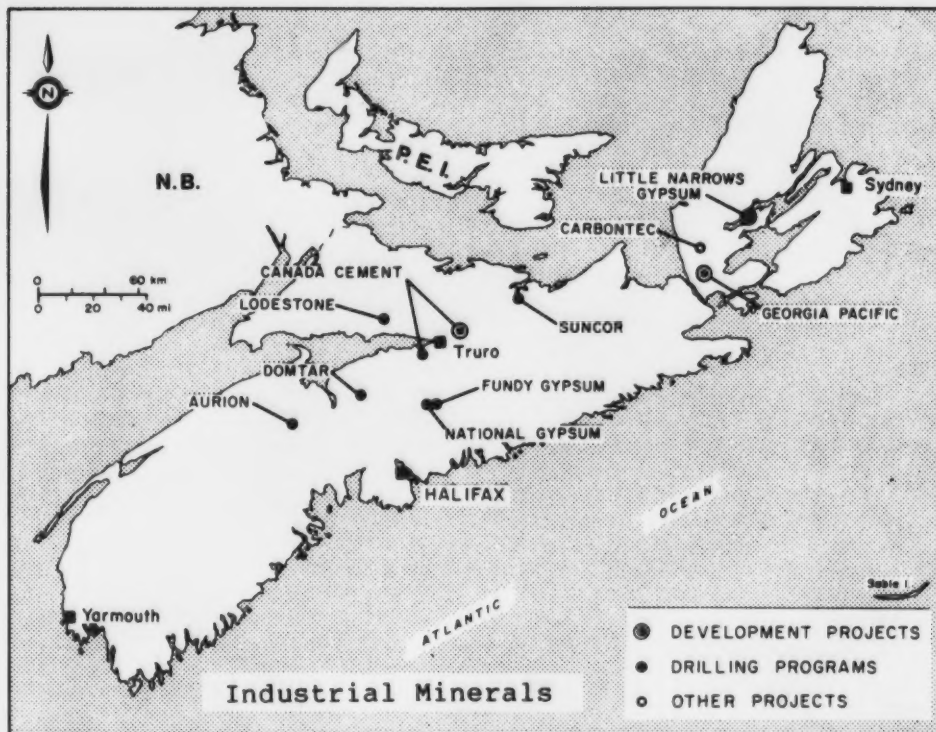


Figure 3. Location of principal exploration and development projects in Nova Scotia, 1987 (industrial minerals and coal).

expand on current reserves.

Exploration for gypsum is concentrated primarily in the Windsor and Milford Station areas in central mainland Nova Scotia. Extensive reserves of gypsum occur in the Lower Carboniferous Windsor Group which underlies much of the area throughout Hants County. Exploration was undertaken by Domtar Incorporated in the vicinity of their quarry at McKay Section east of Windsor, by National Gypsum in the vicinity of their quarry near Milford Station, and by Fundy Gypsum at Dutch Settlement.

Exploration for limestone was undertaken by Canada Cement Lafarge Limited in the Maitland area, Hants County. The company is currently

examining a number of limestone occurrences and has completed ground geophysical surveys, overburden drilling and diamond-drilling on several properties. The company currently operates a cement plant at Brookfield, 18 km south of Truro.

Several other industrial mineral commodities are also being examined including graphite, magnetite and manganese. Carbontec Industries Limited continued an exploration program for graphite at Glendale, Inverness County, and Lodestone Limited completed ground geophysics and diamond-drilling totalling 300 m on a magnetite property 7 km north of Bass River, Hants County. Aurion Minerals Limited completed a small underground

sampling program for manganese on the old Cain property 5.5 km northeast of Aldersville, Lunenburg County.

COAL

Exploration for coal continued on the Suncor Incorporated coal project at Plymouth, Pictou County. Under an option agreement with Suncor, Placer Development Limited completed additional diamond-drilling totalling 2180 m in the New Glasgow area as part of a detailed evaluation of the coal reserves developed to date by Suncor.

MINING DEVELOPMENT

GOLD

Development work was carried out by Seabright Resources Incorporated on the Forest Hill gold property in Guysborough County and the Beaver Dam gold property in Halifax County during 1987. The company completed a 230 m exploration shaft on the Forest Hill property in 1986 and started bulk sampling on the -200 m level. The work continued in 1987 and included underground diamond-drilling and extensive drifting and crosscutting to access auriferous zones encountered in the surface drilling program. The work concentrated on the -200 m level with some work on the -150 m level. Bulk samples were trucked to Gays River for processing at Seabright's regional mill facility. Similar work was also undertaken by Seabright at the Beaver Dam property to evaluate the results of extensive drilling on the property. The company started the construction of a decline in 1985 to facilitate an underground diamond-drilling and bulk sampling program.

Coxheath Gold Holdings Limited

began an underground exploration and development program on the Tangier gold property in Halifax County. The construction of a decline was started early in the year to facilitate underground diamond-drilling and bulk sampling program. In addition to the continuing underground program, the construction of a mill was also underway during the fall.

INDUSTRIAL MINERALS

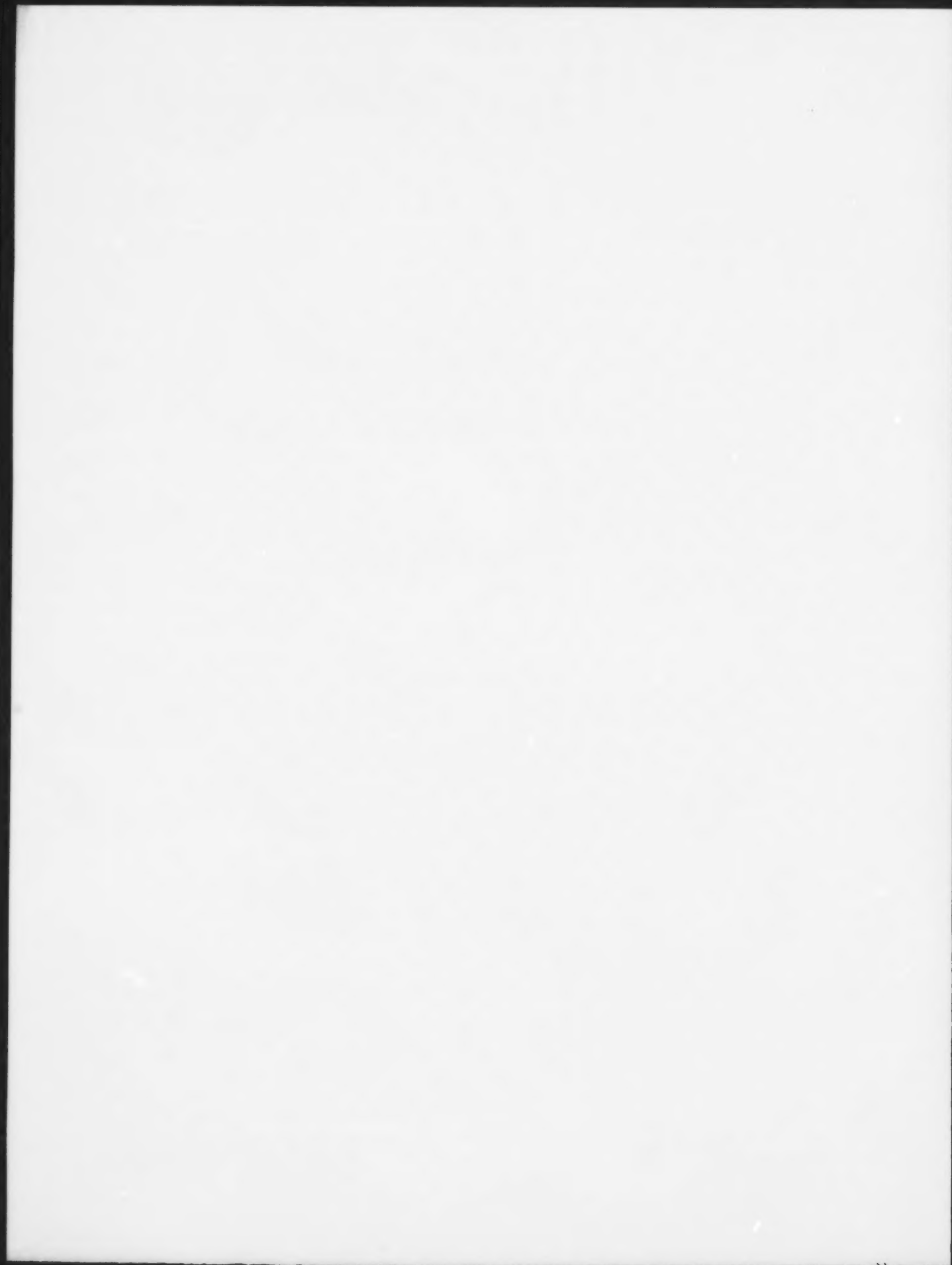
Development projects for gypsum were carried out at two principal properties on Cape Breton Island. anLittle Narrows Gypsum Company continued development drilling to expand on current reserves at their Little Narrows deposit 14 km east of Whycocomagh and Georgia Pacific continued development drilling at their Sugar Camp deposit 12 km northeast of Port Hawkesbury. The Sugar Camp deposit has recently been brought into production.

Canada Cement Lafarge Limited completed development drilling for limestone at Manganese Mines 11 km east of Truro during 1987. The work is part of a continuing program to develop high calcium limestone reserves in central mainland Nova Scotia. Mosher Limestone Company Limited completed the final stages of development work, including the construction of a mill, on the Kelly Cove limestone-dolomite property 35 km northeast of Baddeck.

COAL

The Cape Breton Development Corporation completed the final phases of surface and underground development work on the Phalen mine during 1987 and began production on the property in the fall.





MEGUMA GOLD STUDIES I: GENERALIZED GEOLOGICAL ASPECTS OF THE BEAVER DAM GOLD DEPOSIT, EASTERN MEGUMA ZONE, NOVA SCOTIA¹

P. K. Smith and D. J. Kontak

INTRODUCTION

The lower Paleozoic Meguma Group of Nova Scotia represents a unique geological terrane hosting numerous gold deposits and occurrences (Fig. 1). Of these, over 60 were developed into active producing districts between 1860 and 1947 with total historical gold production just over 1,000,000 oz. (Bates, 1987) from relatively shallow (<300 m) underground, narrow, high grade vein operations. Renewed gold

exploration in Nova Scotia has resulted in the discovery of significant new gold reserves around former gold districts and the identification of several other previously unrecognized auriferous zones.

Numerous genetic models have been proposed for the origin of these turbidite-hosted vein gold deposits. These models include: (1) the classical "saddle-reef" (Faribault, 1926; later reiterated by Keppie, 1976), (2)

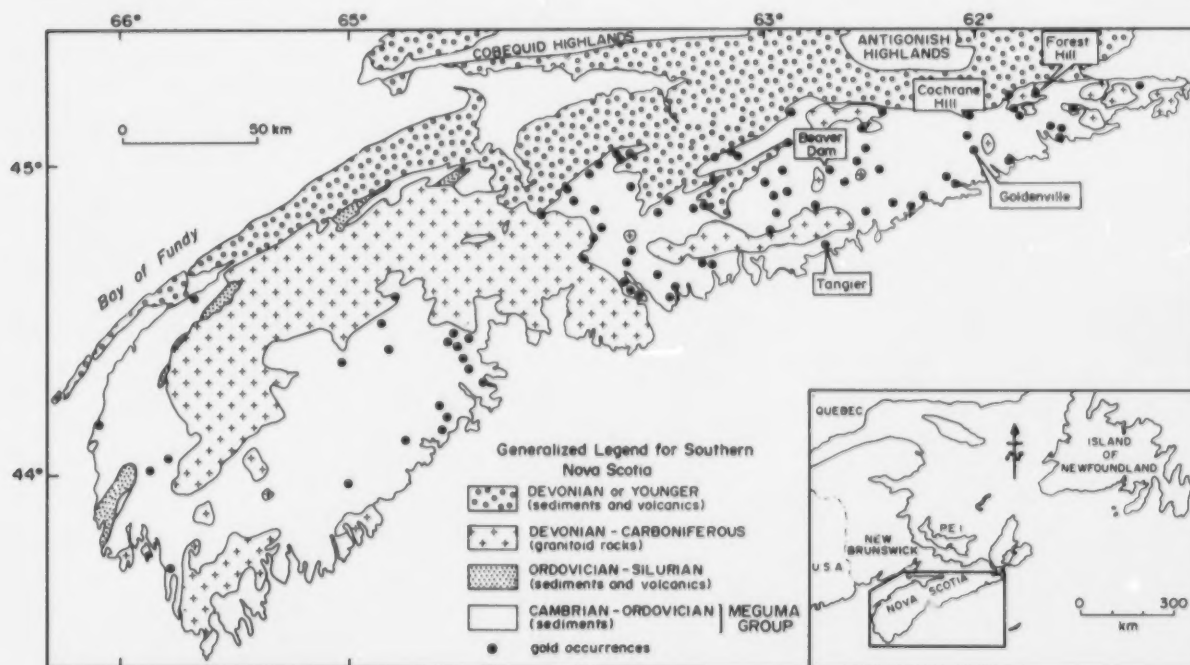


Figure 1. The Meguma Terrane of Nova Scotia.

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

granite-derived (Newhouse, 1936), (3) exhalative (Haynes, 1983; 1987), (4) hydraulic fracturing and lateral secretion accompanying regional deformation (Graves and Zentilli, 1982; Clifford et al., 1983; Henderson and Henderson, 1987; Henderson, et al., 1986; Hy, 1987) and (5) granite-related polygenetic models (Smith, 1983; Smith et al., 1985). This study is designed to evaluate the geological aspects of the Meguma Group gold deposits to help constrain a workable genetic model. Preliminary work involving the examination of 30 past and currently producing districts demonstrated that these gold deposits could not be explained precisely by any of the above models, although a close temporal association with the granitoid intrusions could not be overlooked. Of the deposits examined, Beaver Dam (formerly of Seabright Resources Inc.; currently Western Mining Corporation) was studied in the most detail (surface, underground and diamond-drill core). It is regarded as typical of most, if not all, Meguma Group gold districts in eastern Nova Scotia.

The following is a brief summary of the major geological features for the Beaver Dam deposit which characterize and restrict applied genetic models for Meguma Group gold deposits.

STRATIGRAPHY

Three dominant stratigraphic units are exposed in underground workings of the Beaver Dam gold deposit. These are, from youngest to oldest, the Austen, Papke and Crouse Zones. These lithological units occur on the south, overturned limb of the Beaver Dam Anticline, striking approximately 110° (Fig. 2) and dipping $70-75^\circ$ northwards. Individual beds within each of the units are continuous along strike throughout the entire underground workings and the overall thickness of each unit remains constant except where local folding or faulting occurs. A

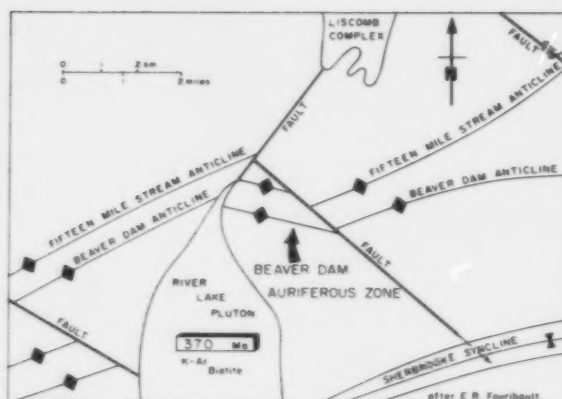


Figure 2. Regional geology of the Beaver Dam gold district.

section through part of the stratigraphy is represented by diamond-drill hole BD-80-4 (Fig. 3).

AUSTEN ZONE

This zone is characterized by a sequence of thin, alternating greenish and bluish, fine grained siltstone interbedded with typical 10 cm - 50 cm thick, variably silicified greywacke. Within this zone a distinctive 20 cm wide silicified calc-silicate bed designated the 'Marker calc-silicate' is recognized throughout the entire deposit. The base of the Austen zone is designated as the base of the lowest 'Millet-seed' greywacke bed (Fig. 3). The top of the Austen zone is placed at the base of a thick sequence of silicified greywacke beds designated as the 'Crusher Lake greywacke' (Fig. 3).

PAPKE ZONE

The Papke zone is characterized by a sequence of very fine grained, dark bluish-black, silty argillites with variably developed bedding-parallel arsenopyrite stringers or veins, termed 'stripes'. Individual stripes are variably folded and average about 1 cm in width. The overall thickness of the striped zone varies considerably in the underground workings. The authors regard this unit as part of an

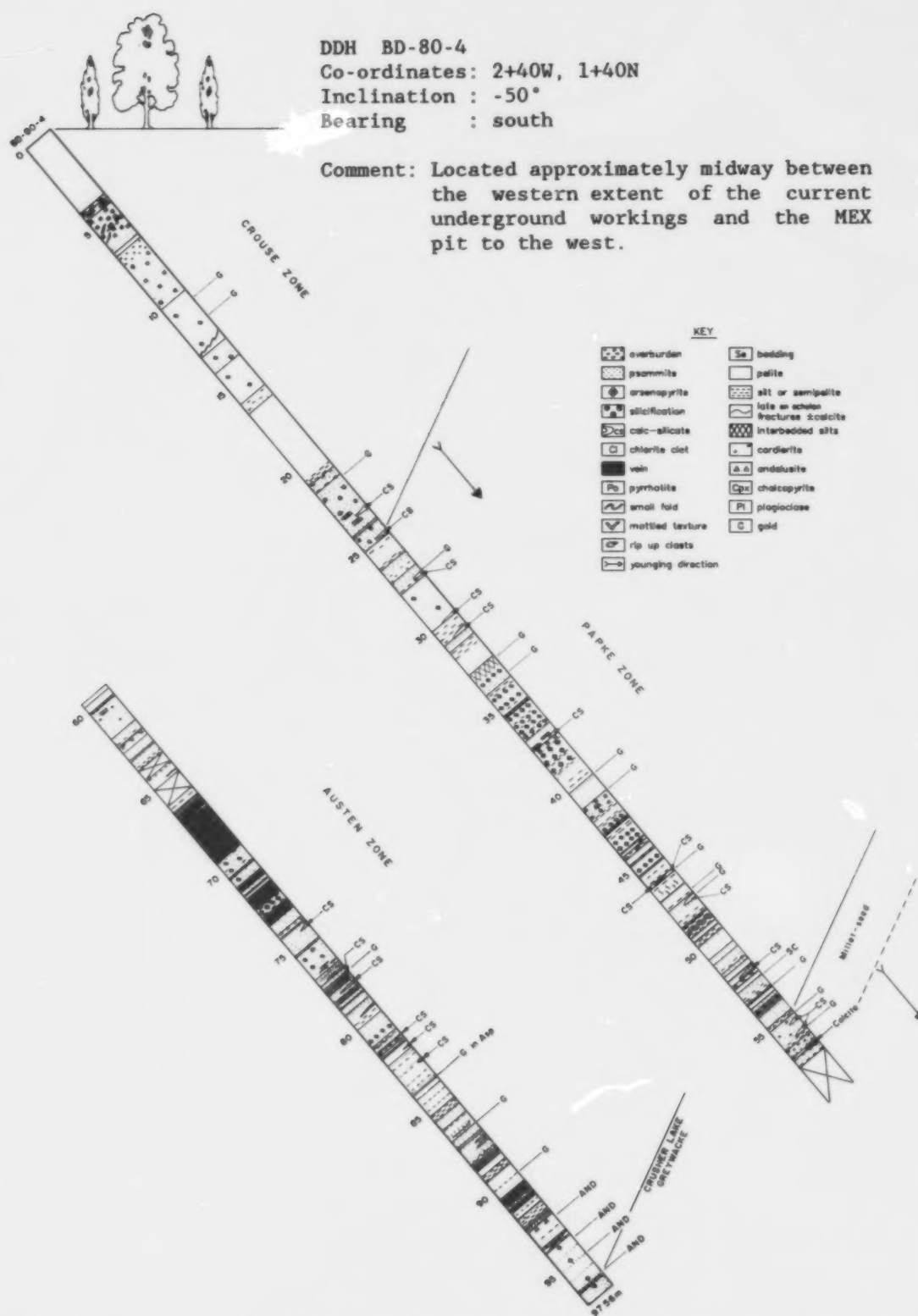


Figure 3. Diamond-drill hole section representative of the stratigraphy of the Beaver Dam deposit.

inherited sulphide alteration assemblage and not as a representative stratigraphic horizon. The Papke zone strata are interbedded with 10-50 cm thick, fine grained, variably silicified greywacke. The stratigraphic top of the Papke zone is established as the base of the lowermost Millet-seed greywacke bed (Austen zone). The base of the Papke zone is designated as the highest calcareous greywacke in the Crouse zone (Fig. 3). The true stratigraphic thickness of the Papke zone is approximately 30 m.

CROUSE ZONE

The Crouse zone is characterized by lower and upper dark bluish-mauve, calcareous, laminated and(or) nodular beds ≈ 1.5 and 0.5 m thick, respectively (Fig. 3). The base of the Crouse zone is not defined at this time. Well developed primary sedimentary structures, such as groove casts, current striations, flute casts and ripple marks are common in the upper section of the Crouse zone (e.g. 1050 m level).

STRUCTURE

Early reports (Malcolm, 1929) around the Beaver Dam deposit suggested that the mineralized zones lie immediately adjacent to the anticlinal hinge of the Beaver Dam Anticline (Fig. 2) over a strike distance of more than 1.6 km. However, surface diamond-drilling indicates that the position of the regional anticlinal fold hinge must be adjusted northwards from its reported position.

A sequence of structural events has been established for the eastern Meguma zone (Smith, 1983; 1986b; Smith et al., 1985; O'Brien, 1983; Keppie, 1983). In the Sherbrooke and Guysborough areas east of Beaver Dam, five deformational episodes associated with the Devonian Acadian Orogeny are defined ($D_1 - D_5$; Table 1). At the

Beaver Dam deposit most of these events are represented. Brief descriptions of some of the structural elements are given in Table 2 and subsequently put into a relative and absolute time frame with regard to veins hosting mineralization (Fig. 4).

METAMORPHISM

Metamorphism throughout the Meguma Group of eastern Nova Scotia is generally regarded as regional in nature, reaching greenschist and lower amphibolite facies (Keppie, 1979). However, our recent studies (Smith, 1983; Kontak and Smith, 1987; Smith and Kontak, 1987) around gold deposits have shown that the metamorphism is not as simple as previously suggested. Regional metamorphism is dated at 415-405 Ma (Reynolds et al., 1987; Reynolds and Muecke, 1978) and post-dates the onset of regional deformation (Taylor and Schiller, 1966). Metamorphic isograds are crosscut by Devonian Carboniferous plutons (at ca. 370 Ma). Some workers have incorrectly suggested that this metamorphism pre-dates deformation (Graves and Zentilli, 1982). At the Beaver Dam deposit, two distinct metamorphic events are recognized based on relative age relationships with other structural elements. The salient features of these metamorphic events are summarized below but represent part of ongoing studies. The relative timing of metamorphism M_1 and M_2 is summarized in Figure 4.

M_1 METAMORPHISM

This metamorphic event is regarded as regional in nature based on its overgrowth relationship with S_2 cleavage. In all cases the metamorphic mineral assemblages are subsequently overgrown and deformed by D_4 structures. At Beaver Dam this regional metamorphism is characterized by biotite locally retrograded to chlorite in pelitic lithologies and

Table 1. Deformational episodes associated with the Devonian Acadian Orogeny.

DEFORMATION	CHARACTERISTIC FEATURES	TYPE OCCURRENCE	OBSERVED AT BEAVER DAM	COMMENTS
D ₁	rare folds, grain alignment cleavages (flat; folded steep)	Sherbrooke	No	variably developed throughout the eastern Megana Zone
D ₂	pervasive regional folds; upright slaty and pressure solution cleavages; pre-regional metamorphism	Quesborough County	Yes	locally cleavages are strongly deformed; no associated minor folds are observed at Beaver Dam; commonly mistaken with D ₄ structures
D ₃	controlled by lithology; no folds; coarse flat biotite foliation; syn-plutonism ~370 Ma	Cochrane Hill and County Harbour	Yes	weakly developed at Beaver Dam in siltstones of the Austen Zone
D ₄	associated with ductile shear zones; numerous folds; strong upright cleavages; deforms metamorphic porphyroblasts; progressive development	Waterville Syncline, Lundy Shear Zone	Yes	dominant upright fabric at Beaver Dam and many other gold districts; axial planar to all minor folds of quartz veins at Beaver Dam
D ₅	crenulations, faults (thrust, reverse, normal, strike slip) kink bands, boudinage	throughout Megana Zone	Yes	post-date gold mineralization; several generations

Table 2. Major symbology applicable to *Meguma Gold Studies I - VI*.

D ₁	: Earliest recognized deformation
D ₂	: Regional deformation
D ₃	: Deformation associated with granitoid plutonism ca. 370 Ma.)
D ₄	: Shear deformation
D ₅	: All deformation post-dating D ₄

S ₀	: Bedding
S ₁	: Early grain alignment cleavage (poorly preserved)
S ₂	: Regional slaty and pressure solution cleavages (pre-dates regional metamorphism - M ₁)
S ₃	: Subhorizontal biotite banding (synchronous with granitoid plutonism ca. 370 Ma.)
S ₄	: Upright shear cleavage (post-dates granitoid plutonism)
S ₅	: Variably oriented crenulation cleavages

M ₁	: Regional metamorphism
M ₂	: Anomalous metamorphism (post-dates regional metamorphic minerals)

P	: Plutonism
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A ₁	: Pervasive alteration (silica, carbonate, phyllic, sulphide)
A ₂	: Local alteration (chlorite, carbonate)

GEOLOGIC HISTORY								
	SEDIMENTATION	GRAIN ALIGNMENT	REGIONAL	HORIZONTAL FOLIATION	PLUTONISM	DUCTILE	SHEAR	BRITTLE
VEIN TYPE	S ₀	D ₁	D ₂	D ₃	P	D ₄	D ₅	
RIBBON			---		●			
STRATABOUND			---		●			
IRREGULAR			---		●			
PEGMATOID					●			
TOURM.-RICH					●			
BULL X					●			
ac			---		●			
M ₁ -REG. MET.			●		●			
M ₂ -ANOM. MET.					●			
A ₁ -ALTERATION					●			
A ₂ -LOCAL ALT.					●			
GOLD					///		??	

Figure 4. Schematic showing the relative age relationships of vein types, metamorphism, alteration and gold mineralization at the Beaver Dam gold deposit.

garnet growth in calc-silicate horizons.

M₂ METAMORPHISM

Dynamothermal metamorphism associated with gold districts in the eastern Meguma Zone (e.g. Cochrane Hill, Forest Hill and Beaver Dam) has locally elevated the metamorphic mineral assemblages to amphibolite facies. At the Beaver Dam deposit this metamorphic event is manifested by coarse grained biotite and chlorite overgrowing earlier fabrics and M₁ metamorphic minerals. Immediately west of the Beaver Dam mineralization, near the River Lake Pluton but not in the contact aureole, high grade mineral assemblages (andalusite, staurolite, cordierite, garnet and biotite) are noted at shallow depths within diamond-drill core sections. Amphibole is common in many of the calc-silicate

horizons. In all cases these minerals overgrow earlier regional metamorphic minerals and fabrics but any single sample may show relative age relationships pre-dating, synchronous with and post-dating S₄ shear cleavage.

Steep elongate mineral lineations on both cleavage and bedding surfaces overgrow S₂ cleavage and are deformed by later S₄ cleavage. Their mineralogy consists of biotite, muscovite, chlorite and quartz with local minor amounts of plagioclase. The relative age relationships of the various structural elements and metamorphic minerals suggest that the M₂ metamorphic event occurred contemporaneously with plutonism (ca. 370 Ma).

ALTERATION

Alteration associated with the gold deposits was first suggested by Smith (1984) who described silicified greywackes at the Cochrane Hill gold deposit in Guysborough County. Subsequently, Smith and Kontak (1987) and Kontak and Smith (1987; in press) documented the first occurrence of massive pervasive alteration (silicification) associated with the Beaver Dam deposit. As well as obvious silicification, the presence of extensive carbonate, phyllic and sulphide alteration associated with many of the gold districts in eastern Nova Scotia was also noted.

At Beaver Dam there are two distinct stages of alteration (A₁ and A₂). The first stage (A₁) is characterized by pervasive silicification, localized sulphide alteration, minor carbonate alteration and minor phyllic alteration. Areal extent of A₁ alteration is approximately 5 km along strike and 1 km across strike. The second stage (A₂) is local alteration less intensely developed than A₁. A brief description of each of the alteration types is given below.

FIRST STAGE (A₁) ALTERATION

Pervasive silicification is restricted to specific horizons and is most easily recognized in greywacke beds that have been selectively bleached from a bluish-grey to a light greenish colour. This alteration has sometimes been mistaken for chert lithologies (Haynes, 1983). Contacts between altered and fresh wall rock may be either diffuse or sharp and can crosscut stratigraphy on a local scale. There is no systematic distribution of silicification relative to the margins of quartz veins. The width of individual silicified zones varies from just detectable to several tens of metres.

In argillite-rich lithologies, silicification exhibits a different appearance. Silicified zones in argillite-rich rocks are greyish-blue and dark black (Fig. 5) in contrast to

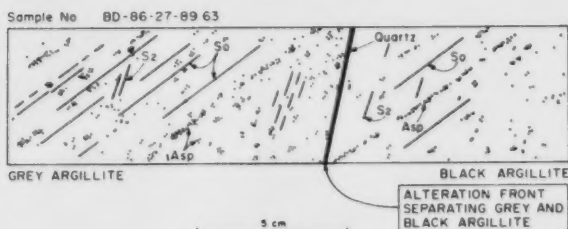


Figure 5. Drill core sample showing sharp alteration front in biotite-bearing, arsenopyrite-rich argillite. Grey argillite is sericite-rich. Arsenopyrite occurs parallel to S_0 and is more abundant in grey argillite (Beaver Dam). S_0 -bedding, S_2 -slaty cleavage, Asp=arsenopyrite.

the bleached zones in greywacke. Commonly this alteration style is parallel to bedding and hence its presence is easily overlooked. However, where it crosscuts bedding at a high angle (Fig. 5) the contact is sharp. Locally, new coarse crystalline

quartz has grown adjacent to quartz veins suggesting that massive wall rock replacement has occurred. This mechanism is suggested for the formation of some of the quartz veins at Beaver Dam and other gold deposits in the Meguma Zone (see *Meguma Gold Studies II*, this volume).

Extensive phyllic alteration at the Beaver Dam deposit is not common. However, it is best observed as pervasive sericite replacement in some of the interbedded greenish and bluish siltstones in the Austen zone.

Carbonate alteration is common at some districts (e.g. Lake Catcha) where it is a major vein component and constitutes up to 70% of some of the wall rock lithologies. At Beaver Dam it is restricted to specific thin (10 to 50 cm) greywacke beds, where it replaces approximately 80% of the original mineralogy. In pelitic lithologies this alteration is limited to the presence of small amounts of disseminated carbonate representing less than 10% of individual beds.

Beaver Dam offers one of the best examples of sulphide alteration in any of the gold districts in the Meguma Zone. The alteration is represented by arsenopyrite + pyrrhotite + pyrite forming a steeply inclined halo in part of the Papke zone. The sulphide alteration crosscuts lithological boundaries, does not continue along strike of individual beds and therefore does not represent a unique stratigraphic horizon. The most easily recognized sulphide alteration assemblage is the previously described arsenopyrite stripes, which have variable relative age relationships to quartz veins. In some cases veins crosscut the arsenopyrite stripes and in other cases the opposite is true (Figs. 6 and 7). The limits of this alteration are not known, but it is observed in deep (~750 m) diamond-drilling on the property and in several other zones towards the north.

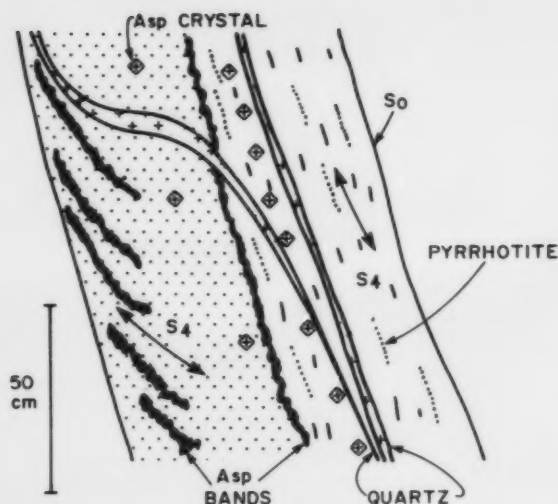


Figure 6. Arsenopyrite bands along S_4 shear cleavage in silty wacke. Beaver Dam, 1040 Level, 16 m along west heading.

SECOND STAGE (A_2) ALTERATION

The second stage alteration (A_2) at the Beaver Dam deposit is not pervasive. This second stage is characterized by orange-beige alteration haloes up to 10 cm wide with diffuse boundaries on either side of thin (1 to 4 mm) calcite-chlorite veinlets (Fig. 8). In general these alteration zones cut across stratigraphy at a high angle, although locally they parallel strata for short distances.

QUARTZ VEINS

Historically, almost all of the reported gold production in the Meguma Group has come from high grade quartz veins. There is no consensus from various studies and authors concerning absolute timing of vein formation (see *Meguma Gold Studies II*, this volume). This has resulted in the diversity of genetic models that have been proposed for the Meguma Group gold deposits.

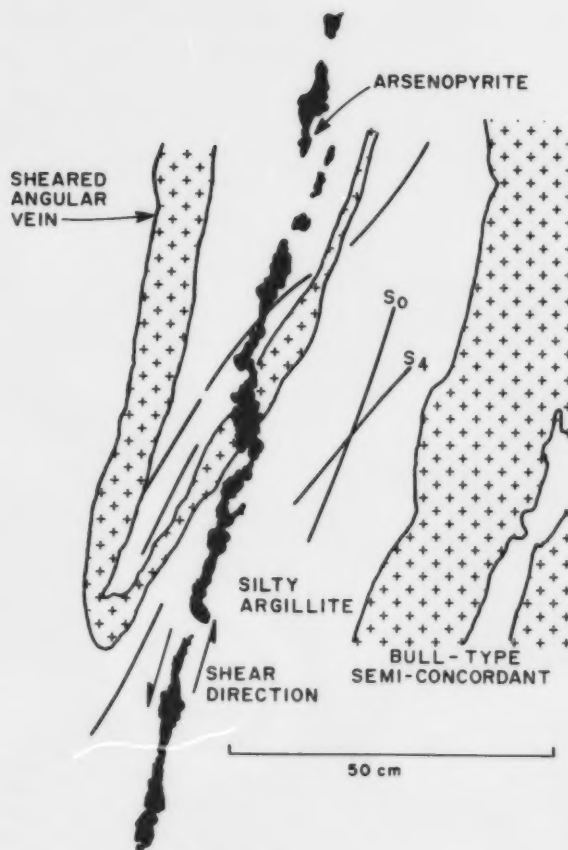


Figure 7. Crossing relationships between angular quartz vein and arsenopyrite stringer. Beaver Dam, 1050 crosscut, east wall.

Detailed vein descriptions and vein chemistry are fully described in subsequent papers in this volume.

A summary of the various vein types and relative age relationships is shown in Figure 4. Two important factors must be considered regarding veins in Meguma Group gold deposits. The first is that they all show a temporal association with Devonian-Carboniferous granitoid plutonism. This observation is supported by absolute dating of vein minerals for the Beaver Dam deposit, in addition to relative age relationships of

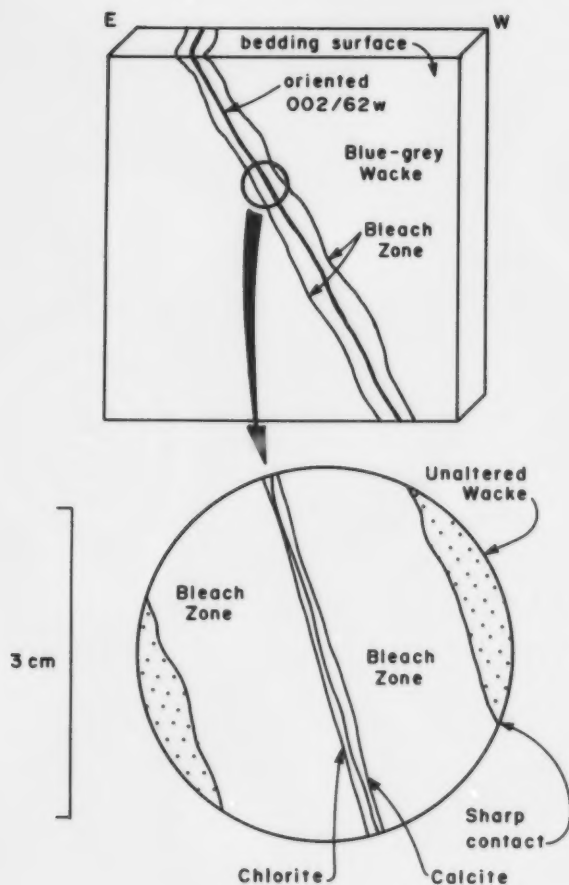


Figure 8. Crosscutting alteration zone with chlorite-calcite core and strong bleached halo in blue-grey unaltered wacke. Beaver Dam, 1050 crosscut, west heading.

metamorphic and structural features. The second important factor suggested from underground and petrographic observations is that many of the veins are the product of massive wall rock replacement and not fracture infilling (Smith and Kontak, 1988), although locally in some veins dilatant fracture infilling is dominant. The implications of this are discussed further in this volume (see *Meguma Gold Studies II*).

MINERALIZATION

Native gold is the dominant ore mineralization associated with the Meguma Group gold deposits. Historically it has been mined from relatively narrow quartz veins from "ore shoots" (Faribault, 1926) oriented at shallow angles in the plane of the veins (e.g. Forest Hill). However, at Beaver Dam the dominant ore zones have a steep easterly plunge (Fig. 9), locally parallel to the sulphide alteration halo (e.g. Papke zone). This observation supports the conclusion that the strata were already deformed into an upright position prior to mineralization.

Gold occurring in quartz veins is both coarse grained (average 1-2 mm) and, to a lesser extent, fine grained (1-30 μm) and exhibits variable textures including crystalline, wiry, amorphous and platy. At Beaver Dam there are two dominant colours to the gold (J. Campbell, personal communication). They include a bright yellow (less dominant) and an orange gold which have no obvious systematic distribution throughout the underground workings. The geochemistry of the two phases is currently under investigation. Euhedral, micron size gold along healed fractures is locally associated with fluid inclusions which crosscut recrystallized quartz grain boundaries (Fig. 10). All observations from Beaver Dam and other gold deposits (e.g. Cochrane Hill, Forest Hill) suggest that the gold formed relatively late in the paragenetic sequence. Definitive textures suggesting remobilization have not been noted. Additionally, there are anomalous concentrations of fine grained gold (1 μm to 1 mm) associated with sulphides throughout some wall rocks. Ore grade values have previously been noted at Cochrane Hill (Smith, 1984; 1986a) and may represent a significant part of the ore body at Beaver Dam and other districts.

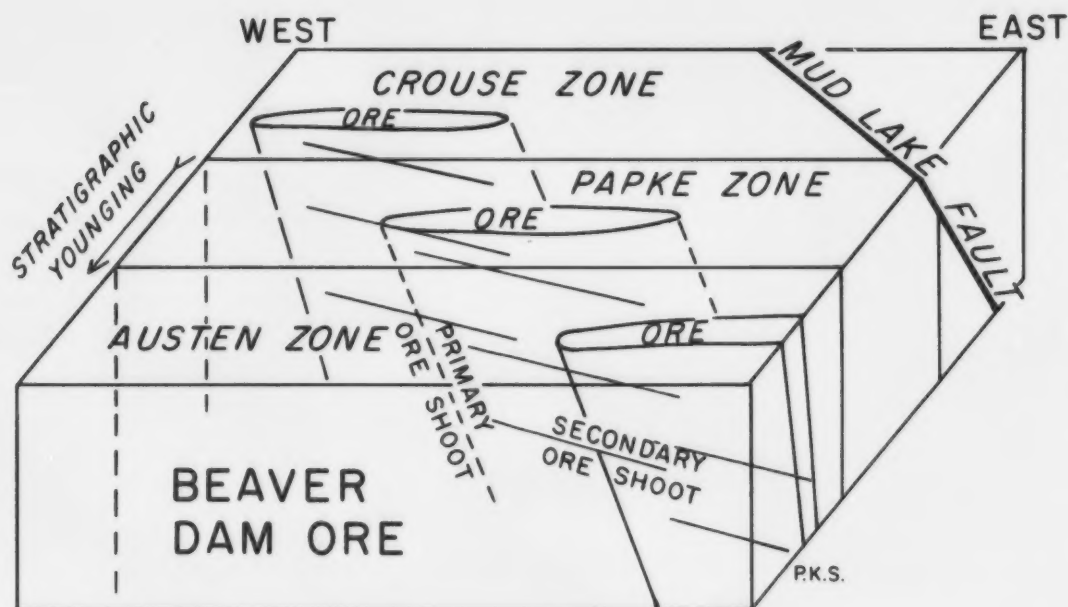


Figure 9. Schematic section of ore zones at the Beaver Dam deposit. Section is not drawn to scale.

Both in veins and wall rock, the gold is observed to cut across regional and dynamothermal metamorphic minerals as well as vein minerals, including biotite, muscovite, garnet, plagioclase, apatite, tourmaline and chlorite. The dominant base metal minerals associated with the gold are galena, chalcopyrite and sphalerite. Other minerals include arsenopyrite, pyrite and pyrrhotite with lesser amounts of other sulphides and oxide minerals.

CONCLUSIONS

The basic conclusions outlined above for the Beaver Dam deposit are as follow: (1) A mappable stratigraphy is recognized which has considerable strike continuity throughout the deposit. (2) The best mineralization is located on the overturned south limb of an asymmetric fold (Beaver Dam

Anticline) with an ill-defined axial trace. (3) Five deformational events are recognized at the Beaver Dam deposit, a fact consistent with other deposits in the Meguma Group. (4) Metamorphism at the deposit is represented by two distinct events, one regional in nature and the other a dynamothermal event contemporaneous with Devono-Carboniferous granitoid plutonism. (5) Two alteration stages are represented within the deposit, the first being the most pervasive with associated silicification, phyllic, carbonate and sulphide alteration, the second being restricted to crosscutting fractures. Both alteration stages overprint metamorphic mineral assemblages. (6) Much of the vein formation in the deposit is attributed to structurally controlled wall rock replacement along D_4 shear zones. These zones were active during and after plutonism. This conclusion for vein formation is based on textural

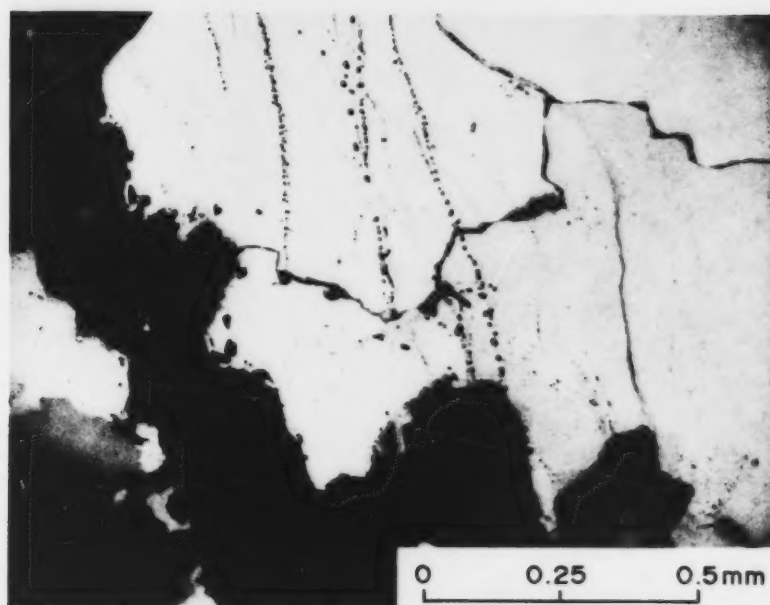


Figure 10. Fracture plane with abundant inclusions of opaque minerals including gold, galena, pyrrhotite and several other phases. Fluid inclusions also occur along these same planes which crosscut recrystallized quartz grains and altered plagioclase.

data and the observation that the stratigraphic thickness is not increased regardless of the amount of quartz vein material present in the section. (7) Gold mineralization occurs both in veins and wall rocks in steeply plunging ore zones.

Based upon the observations above, we conclude that several of the previously proposed genetic models (e.g. exhalative, saddle-reef, lateral secretion) do not adequately explain the Meguma Group gold deposits. A model which more closely portrays the genetic evolution of the gold deposits in the Meguma Group of eastern Nova Scotia is elaborated upon more fully in this volume (see *Meguma Gold Studies VI*).

ACKNOWLEDGMENTS

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MEGUMA GOLD STUDIES II: VEIN MORPHOLOGY, CLASSIFICATION AND INFORMATION, A NEW INTERPRETATION OF "CRACK-SEAL" QUARTZ VEINS¹

P. K. Smith and D. J. Kontak

INTRODUCTION

The lower Paleozoic Meguma Group of Nova Scotia offers tremendous potential for both high and low grade, large tonnage gold deposits. Although historically the majority of gold production (~1.2 million ounces; Bates, 1987) came from relatively narrow (<1 m) quartz veins (Malcolm, 1929), the recent exploration boom in this Province has demonstrated the presence of significant quantities of low grade ore concentrated in metasedimentary host rocks over substantial mining widths (up to 30 m). This will, without doubt, firmly establish Nova Scotia's reputation as a world class gold province.

Because quartz veins have played such an important role in historical gold production, they have received considerable study in recent years (Graves and Zentilli, 1982; Haynes, 1983, 1986, 1987; Keppie, 1976, 1983; Henderson et al., 1986; Henderson, 1983; Clifford et al., 1983; O'Brien, 1983; Mawer, 1986; Hy, 1987). All of these studies concluded that all quartz veins, and hence mineralization, were introduced prior to, or synchronous with, regional fold development during the Devonian Acadian Orogeny. Various genetic models proposed for these deposits, including saddle-reef (Faribault, 1926; Keppie, 1976), exhalative (Haynes, 1986), hydraulic

fracturing (Graves and Zentilli, 1982) and lateral secretion from a unique stratigraphic horizon (McBride, 1978), have all evolved on the basis of vein-only examination. However, during recent examination of multiple geological parameters associated with the Meguma Group Gold districts, Smith and Kontak (1987; and this volume) reinterpreted new and existing data to suggest that the gold mineralization and host quartz veins had an intimate temporal association with Devonian granitoid plutonism throughout southeastern Nova Scotia. A similar conclusion was presented by Newhouse (1936) who interpreted the gold deposits as spatially distributed around the margins of the granitic plutons. Smith and Kontak (1987) further suggested that wall rock replacement associated with high fluid/rock ratios during ductile shear deformation was largely responsible for quartz vein formation in the Meguma Group gold districts. For this reason a brief description of critical information about quartz veins in the Meguma Group gold deposits of eastern Nova Scotia is given below. These data are consistent with the new genetic model for these turbidite-hosted ore deposits. Additional data supporting this working genetic model are presented in a series of papers in this volume (see *Meguma Gold Studies I-VI*). It is advised that *Meguma Gold Studies I* be read prior to this paper for clarification of terminology.

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QUARTZ VEINS

At present Forest Hill, Cochrane Hill, Beaver Dam, Caribou and Tangier (Fig. 1) offer the best opportunity to characterize vein features associated with auriferous zones. Although only diagnostic features from these deposits are mentioned here, similar observations were made at 26 other gold districts in the eastern Meguma Zone. Preliminary investigation of gold deposits west of Halifax indicate similar observations.

Veins at all deposits have been classified in a similar fashion. Distinguishing features used to classify the various vein types include: (1) relative age relationships of veins with metamorphic and structural elements, (2) morphology, (3) mineralogy and (4) texture. Vein populations having different morphology, but uniform texture,

mineralogy and relative age relationships are commonly grouped together for simplicity. This is particularly true for veins with irregular geometry. Variation of vein features between deposits may be partially attributed to variations in the host rock lithology.

Prior to any further discussion of gold deposit vein types, a general understanding of regionally developed vein types is required. O'Brien (1983; 1985) and Henderson et al. (1986) documented regional vein formation throughout the Meguma Group during regional deformation (D₂; see *Meguma Gold Studies I*: this volume). Regional vein types are summarized into four basic categories: (1) bedding parallel, (2) en echelon, (3) irregular discordant and (4) AC. These ubiquitous veins are characterized by quartz-carbonate-chlorite mineralogy. The volumetric proportion of these veins is very limited and their

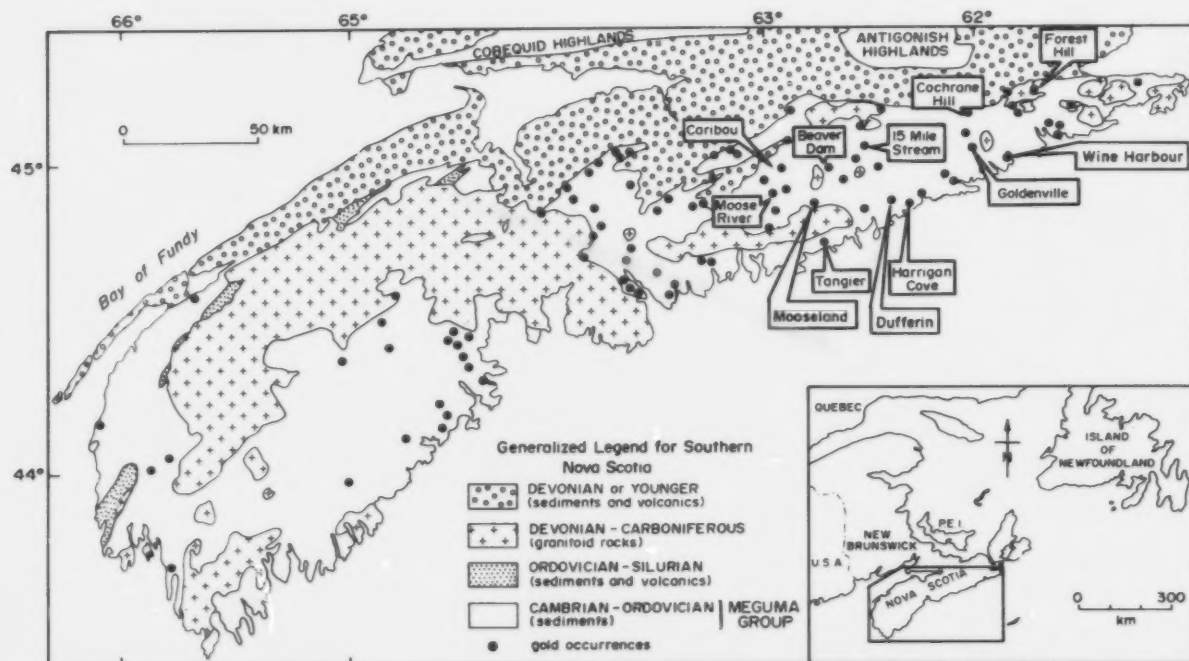


Figure 1. Generalized geological map of southern Nova Scotia showing gold districts (black dots) and the location of those referred to in the text.

formation history can not be temporally or genetically correlated with vein formation in the gold deposits. These regional veins form in response to regional deformation and metamorphic dewatering reactions. Veins formed by these processes are noted in many metamorphic regions throughout the world (Yardley, 1986). However, the voluminous quartz veins and alteration zones associated with the Meguma Group gold deposits (Smith, 1986a) occurred subsequent to regional vein formation. No regional-type quartz veins in proximity to gold deposits have yet been distinguished. However it is reasonable to assume that structural sites favorable for early regional vein formation (bedding parallel and irregular veins) were also present during formation of gold deposit quartz veins at 370 Ma (see *Meguma Gold Studies I and III*: this volume). Data which dictate the temporal relationships of these auriferous veins are presented in this paper.

VEIN TYPES

The vein types discussed below are characteristic of Forest Hill, Cochrane Hill, Beaver Dam, Tangier, Caribou, Goldenville, Mooseland, Moose River and Harrigan Cove gold districts (Table 1, Figs. 2 and 3). Similar vein types are present at other Meguma Group gold districts but have not yet been classified at these localities. Additional complexities in vein classification are outlined by Haynes (1983) and Smith (1983).

RIBBON VEINS

These veins are most commonly referred to as the "crack-seal" type although other names are frequently used to describe them, including: laminated, bedding parallel, stratiform, interbedded, speckled-hen and ribbon. In this paper "ribbon" is the preferred terminology as its name is less subject to conjecture. The formation mechanism of ribbon veins has

generally been argued as critical for establishing genetic models for these gold deposits (e.g. Graves and Zentilli, 1982; Haynes, 1987). However, they probably represent the most poorly understood vein type in these deposits. Clarification of some observations from ribbon veins may help in defining their mechanism of formation.

Ribbon veins are composite, representing at least two distinctive episodes of quartz emplacement, and are characterized by their nearly bedding parallel geometry and laminar texture. This laminar texture consists of residual and fragmental wall rock material as well as single platelet phyllosilicates, generally white mica, included within the vein. Individual crystal size of quartz grains is large (~0.5-1.0 cm in diameter and up to 15 cm in length) and quartz crystals are not always confined between the vein walls (recrystallization reduces grain size in this and all other vein types).

Ribbon veins are always restricted to pelitic host rocks, suggesting a strong lithological control of vein textures. These veins display a multiple formation mechanism including wall rock replacement and open space filling. Vein margins may be sharp or diffuse. Where they are diffuse it is common to observe coarse grained euhedral to subhedral quartz growing perpendicular (or nearly so) to vein/wall rock margins. These crystals possess variable amounts of residual wall rock inclusions which have parallel alignment with the wall rock fabric. Residual inclusions consist of graphite, phyllosilicate and wall rock. This quartz crystal growth closely resembles that of static metamorphic porphyroblasts (i.e. garnet, staurolite, andalusite). Where this quartz growth is best developed, the texture closely approximates that observed in the central portions of some ribbon veins. This strongly suggests that a significant part of

Table 1. Characteristics of major vein types in Meguma Group gold deposits, eastern Nova Scotia.

VEIN TYPE	GANGUE MINERALS	ORE MINERALS	CHARACTERISTIC VEIN FEATURES
Ribbon	qtz - wall rock - carb - mu - bi - tourm - ch $\pm$ gt	Au - Asp - Po - Py - Cpx - Gal - Sph	- So parallel, composite, laminar texture, abundant wall rock inclusions
Stratabound	qtz - wall rock - plag - carb - tourm - bi - mu - gt - ch - ep - amph	Au - Asp - Po - Py - Cpx - Gal - Sph	Bedding concordant, massive white quartz
Irregular, en echelon etc.	qtz - wall rock - mu - plag - carb - ch	Au - Asp - Po - Py - Cpx - Gal - Sph - W	Variable geometry, massive white quartz
Pegmatoid	qtz - plag - co - and - st - carb - gt - bi - mu - ep - wall rock - amph - ch	Au - Asp - Py - Po - Cpx - Gal - Sph	Andalusite and garnet common, abundant plagioclase, coarse muscovite, semi-concordant geometry
Tourmaline-rich	qtz - plag - bi - mu - tourm - gt - ch	Po - Py - Asp - W	Boundinaged discordant, persistent tourmaline, coarse crystalline to fine grained recrystallized quartz
Bull crosscutting	qtz - plag - bi - mu - wall rock - ch - tourm	Au - W - Asp - Py - Po - Gal - Spx - Cpx - (Bi:Ag:Te)	Large transgressive geometry, very coarse grained
ac	qtz - carb - ch $\pm$ (gt - amph - mu - bi)	Au - Asp - Py - W - (Bi:Ag:Te) - (Gr)	Perpendicular to strike, bleached alteration haloes locally

qtz = quartz, carb = carbonate, mu = muscovite, bi = biotite, tourm = tourmaline, gt = garnet, ch = chlorite, plag = plagioclase, ep = epidote, amph = amphibole, Au = gold, Asp = arsenopyrite, Po = pyrrhotite, py = pyrite, Cpx = chalcopyrite, Gal = galena, Sph = sphalerite, W = scheelite, Bi:Ag:Te = Bismuth and silver tellurium complexes, Gr = greenokite

GEOLOGIC HISTORY	SEDIMENTATION						
	GRAIN ALIGNMENT		REGIONAL		HORIZONTAL FOLIATION		PLUTONISM
VEIN TYPE	S ₀	D ₁	D ₂	D ₃	P	D ₄	D ₅
RIBBON							
STRATABOUND							
IRREGULAR							
PEGMATOID							
TOURM.-RICH							
BULL X							
ac							
M ₁ -REG. MET.							
M ₂ -ANOM. MET.							
A ₁ -ALTERATION							
A ₂ -LOCAL ALT.							
GOLD							

Figure 2. Geological history of vein types, metamorphism (M₁-M₂), alteration (A₁-A₂), plutonism (P) and mineralization relative to deformational episodes (D₁-D₅). The reader is referred to *Meguma Gold Studies I* (this volume) for a detailed account of these features.

ribbon veins form by a replacement mechanism. This formation mechanism helps to explain vein textures as well as constant stratigraphic thickness, regardless of the volume of vein quartz, measured at some deposits (Fig. 4). A dilatant crack-seal mechanism resulting from repeated hydraulic fracturing is inconsistent with textural observations.

A second stage of ribbon vein development always present consists of massive white quartz occurring as either replacement overgrowth or as minor dilatant fracture infillings. At the Caribou deposit it has been documented that this secondary quartz emplacement occurs consistently along the ribbon veins producing a composite vein texture (Smith, 1984). Without exception, the authors have only observed native gold in the massive white type of quartz in ribbon veins.

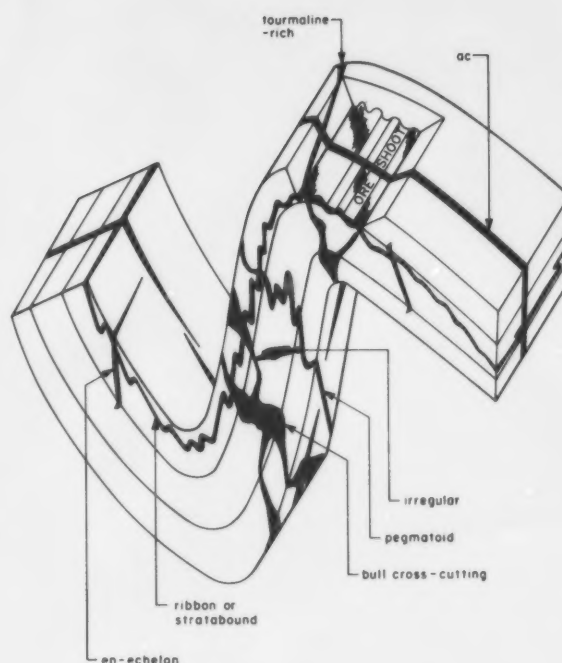


Figure 3. Three-dimensional schematic representing the relative distribution of major vein types within a folded strata. No scale implied.

In general the mineralogy of ribbon veins is simple, with quartz the dominant phase, particularly in the purely laminated part of the vein. In the massive composite part of the vein, or in later boudinage structures, carbonate frequently becomes a major constituent. Other silicate minerals include minor biotite, muscovite, chlorite, tourmaline and plagioclase. Associated ore minerals include gold, arsenopyrite, pyrite, pyrrhotite and base metal sulphides. Minor amounts of oxide minerals (rutile and ilmenite with exsolution of hematite) are generally rare in ribbon veins.

Bedding parallel veins with similar textures have been described by Henderson et al. (1986) from regional studies within the Meguma Group. Smith and Kontak (1988; and this volume) have presented data that suggest much of

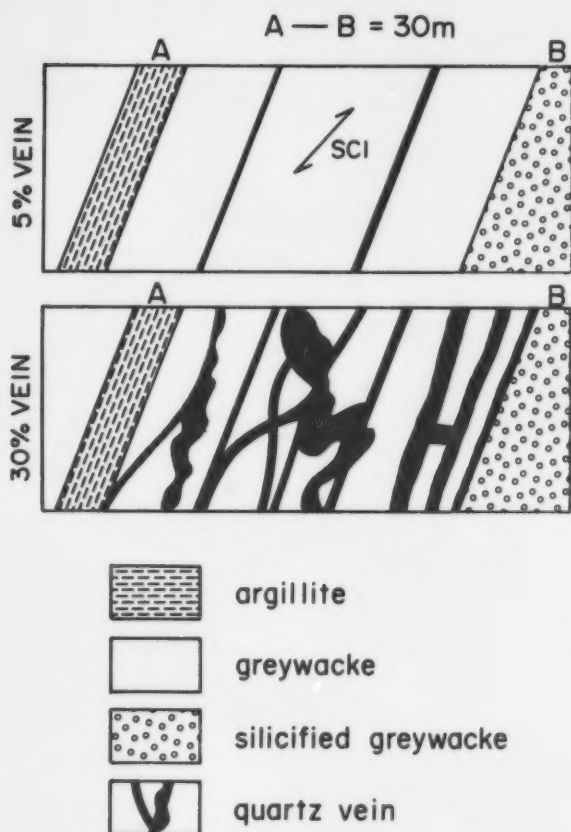


Figure 4. Schematic representation of constant stratigraphic thickness between two marker beds (A and B) regardless of the percentage of quartz veining present. This is a general example from the underground workings at Beaver Dam.

this vein formation was the result of massive wall rock replacement and not hydraulic fracturing. This replacement origin accounts for textural, structural and temporal relationships observed in the field.

STRATABOUND VEINS

This terminology is used for massive white quartz veins that are confined within a particular stratigraphic bed and are generally

parallel to the bedding, or crosscut it at a low angle. Textually the quartz is similar to the massive white quartz in the ribbon veins. Along strike these veins frequently transform into narrower ribbon type veins or become an integral part of them, suggesting contemporaneous vein formation. Where the two vein types merge the resulting thickness equals the combined thickness of each vein.

Mineralogy is dominated by quartz although locally other common vein constituents include biotite, chlorite, muscovite, plagioclase, carbonate, tourmaline, apatite, amphibole and garnet as well as wall rock fragments. Ore mineralogy is similar to that of the ribbon veins although the relative proportions vary.

Mineralogy in this vein type is more complex than in the ribbon veins, locally reflecting bulk wall rock composition. This suggests significant fluid/wall rock interaction during vein formation. Wall rock replacement is observed along parts of these veins and may account for much of the vein formation. These effects are most easily observed where veins overprint metamorphic porphyroblasts (Fig. 5). Frequently, the porphyroblasts (e.g. garnet) show variable stages of *in situ* replacement from partial to complete.

IRREGULAR VEINS

This classification of veins incorporates a number of vein geometries with similar textures, mineralogy and relative age relationships. En echelon veins described by Henderson et al. (1986) may represent a separate category of this vein classification.

The mineralogy of irregular veins is dominated by quartz with lesser amounts of carbonate, chlorite, muscovite and tourmaline. Ore minerals are similar to those of ribbon veins but base metal sulphides and gold are

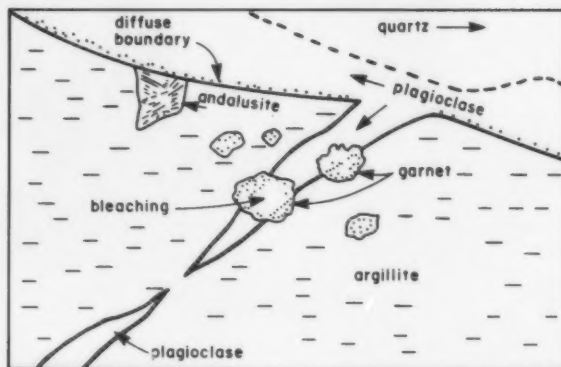


Figure 5. Stratabound vein showing replacement of wall rock by plagioclase (An₄₅). Garnet porphyroblasts are bleached and partially replaced within the plagioclase portion of the vein. Garnets are about 4 mm in diameter.

less common. Although these veins display a significant component of wall rock replacement at their margins, their overall geometry and crosscutting relationships suggest they formed largely as a result of brittle fracture infilling. Where these veins are small (<1 cm), replacement is the dominant mechanism of formation.

PEGMATOID VEINS

This vein type was first described by Smith (1983) at Cochrane Hill for auriferous veins characterized by andalusite. These veins are both concordant and slightly discordant to bedding and have extremely variable silicate mineralogy similar to some of the crosscutting bull veins described below. In addition to andalusite other minerals include plagioclase, biotite, muscovite, chlorite, amphibole, tourmaline, garnet, apatite, epidote, carbonate, staurolite and locally cordierite at the vein margins. Pegmatoid vein mineralogy closely reflects adjacent wall rock mineralogy and bulk rock chemistry (i.e. if high alumina rocks form the wall rock then the vein mineralogy will include

alumino-silicates; if the wall rock is carbonate-rich then the vein will include an abundance of carbonate minerals). Forest Hill offers good examples of this characteristic and shows massive wall rock replacement (Fig. 6). Associated ore minerals are similar to those of the ribbon veins, although the relative proportions vary.

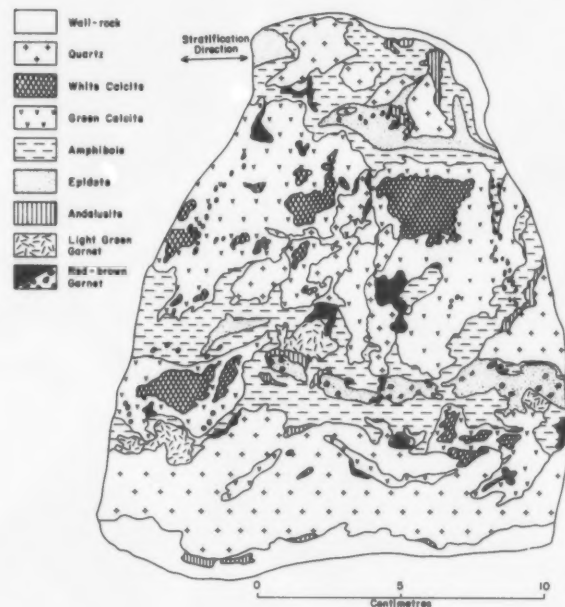


Figure 6. Sketch of a stratabound pegmatoid vein displaying *in situ* replacement texture of calcareous alumina-rich pelite. This sample was collected from the 200 m level (Teasdale shaft) at Forest Hill (cross-sectional view).

TOURMALINE VEINS

Although tourmaline occurs with or adjacent to all vein types, two factors distinguish the tourmaline-rich veins. First, these veins have a higher than normal tourmaline content (30-60% locally) and second, they have a vertically boudinaged discordant morphology. These veins are oriented

subparallel to or slightly steeper than slaty cleavage (e.g. Beaver Dam and Forest Hill gold districts; Fig. 7). Characteristic vein minerals include quartz, plagioclase, tourmaline, carbonate minerals, garnet, biotite, muscovite, amphibole, chlorite and apatite. Associated ore minerals include pyrite, pyrrhotite, arsenopyrite and locally abundant scheelite and base metal sulphides.

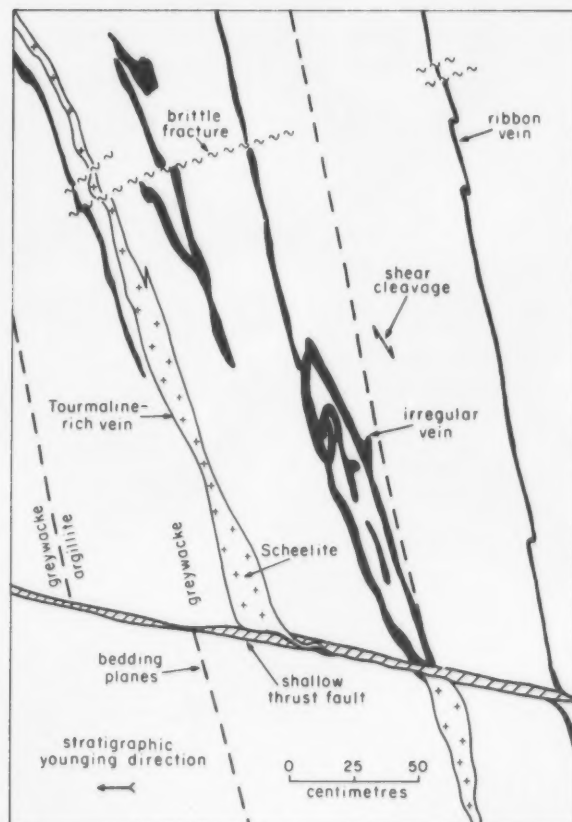


Figure 7. Tourmaline-rich vein on the west wall of the 1050 m level at Beaver Dam. The vein is discordant to bedding and boudinaged. Subhorizontal thrusting displaces the top of the vein to the south.

BULL CROSSCUTTING VEINS

The largest of the veins are crosscutting bull-type quartz veins.

These veins are characterized by discordant geometry (Fig. 8) and the large (up to 30 cm) size of euhedral quartz crystals. At Beaver Dam these veins transect stratigraphy along strike and dip northward slightly shallower than bedding. Along strike these veins display considerable variation in thickness (absent to >5 m) and crosscut all vein types mentioned thus far. Contact relationships between veins are commonly unclear and thus relative age relationships are uncertain. Vein mineralogy is dominated by quartz although near the vein margins abundant plagioclase and biotite are present. Clots of granular chlorite, representing altered wall rock, and crystalline carbonate occur within the vein. Tourmaline and coarse- to fine-grained scheelite are also present locally. Wall rock assimilation and replacement is common at vein margins. Similar characteristics are observed at other gold districts of the Meguma Group (e.g. Fifteen Mile Stream, Moose River). Associated ore minerals include pyrrhotite, pyrite, arsenopyrite, base metal sulphides and trace amounts of gold. Similar geometry and mineralogy (except andalusite) suggest that these veins may be equivalent to the pegmatoid veins described earlier.

AC VEINS

These veins are distinguished from all other vein types by their high angle crosscutting orientation (Fig. 9). They are common both within and outside gold districts (Henderson et al., 1986) and represent at least two relative ages (Fig. 2). Around some deposits (e.g. Wine Harbour) ac veins pre-date regional pressure solution cleavage whereas at others (e.g. Beaver Dam, Tangier, Cochrane Hill, Forest Hill) they post-date regional D_2 deformation (see *Meguma Gold Studies I* for structure terminology). Where the ac veins post-date D_2 regional

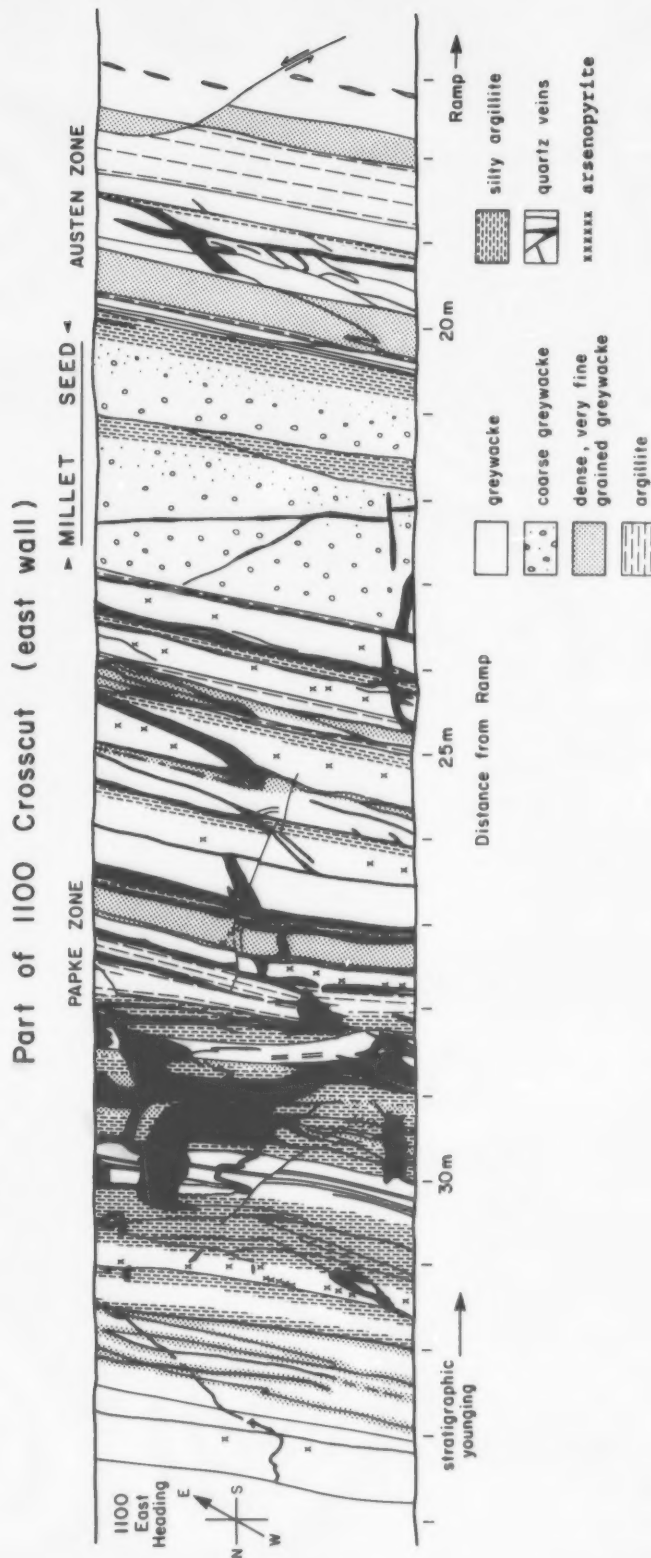


Figure 8. Part of the east wall of the 1100 m crosscut at Beaver Dam showing a large bull crosscutting vein in the Papke zone. Note the relatively undisturbed stratigraphic thickness of bedding where it is intersected by the vein. The "Millet Seed" greywacke beds define the contact between the Papke and Austen zones.

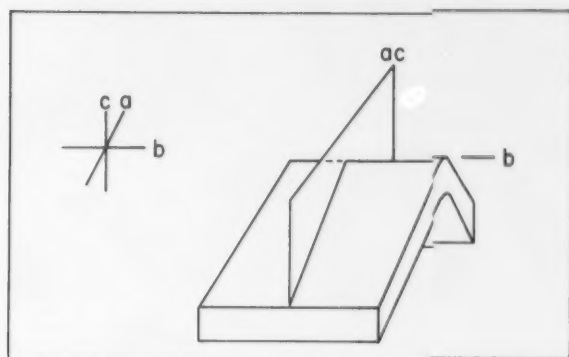


Figure 9. Relative orientation of ac type vein to fold geometry. Fold axis is parallel to b.

deformation, relative age relationships show the veins to pre-date, be synchronous with, and post-date D_4 deformation. Ac veins that pre-date or are synchronous with D_4 deformation display variable amounts of folding and locally have complex mineralogy consisting of quartz, plagioclase, biotite, muscovite, tourmaline, garnet and scheelite with variable sulphide content. Bismuth and silver tellurium complexes have been identified in these veins (e.g. Beaver Dam, Forest Hill). Younger, undeformed ac veins vary dramatically in width (<1 mm - 1 m) and have simple mineralogy (quartz $\pm$ chlorite). Many late stage ac veins post-date pervasive alteration (see *Meguma Gold Studies I*) and display a spatial association to the margins of stratabound and pegmatoid veins. Pyrite is the dominant sulphide mineral although arsenopyrite is present in places. Gold is a common constituent in small, undeformed ac veins (e.g. Cochrane Hill) and occurs in small amounts in larger, deformed ac veins.

STRUCTURE OF VEINS

Relative and absolute age relationships of the veins are critical for an appreciation of the structure associated with the gold districts. First, relative age relationships show

that voluminous vein emplacement of the gold deposits occurred subsequent to regional metamorphism (M_1) at 415 to 400 Ma (Reynolds and Muecke, 1978; Reynolds et al. 1987) and prior to ductile shear cleavage (S_4) associated with D_4 deformation. Second, absolute age dating of the veins (370 Ma, see *Meguma Gold Studies III*: this volume) verifies that they are synchronous with Devonian-Carboniferous granitoid plutonism. Both these factors constrain the age of folding of these quartz veins in the gold districts to D_4 deformation.

At most deposits, the minor fold geometry of veins and bedding is sympathetic to major D_2 regional folds. A notable exception occurs at Forest Hill where folded quartz veins have reverse geometry to D_2 structures. Here, minor D_4 shear folds of quartz veins indicate a major fold hinge to the south whereas the regional F_2 anticlinal fold hinge occurs to the north based on stratigraphic younging direction and S_2 cleavage relationships (Fig. 10). Asymmetric F_4 shear folds have gently plunging east or west fold axes. Associated intersection lineations are generally coaxial with regional bedding/cleavage intersection lineations. Regional cleavage is folded around quartz vein hinges substantiating the view that these veins post-date regional S_2 deformation. Well developed, subhorizontal shear lineations in ribbon type quartz veins indicate extensive horizontal tectonics synchronous with and post-dating vein formation. Vertical shear lineation, horizontal shear fold axes and vertical boudinage support substantial vertical movement.

Late stage brittle deformation (D_5) is manifest by faults, kink bands and crenulations. These structures deform all vein types, although at Forest Hill and Caribou new vein material (quartz and chlorite) occurs in dilatant areas (true 'saddle-reef'

structures) of tight F_5 kink folds (Fig. 11).

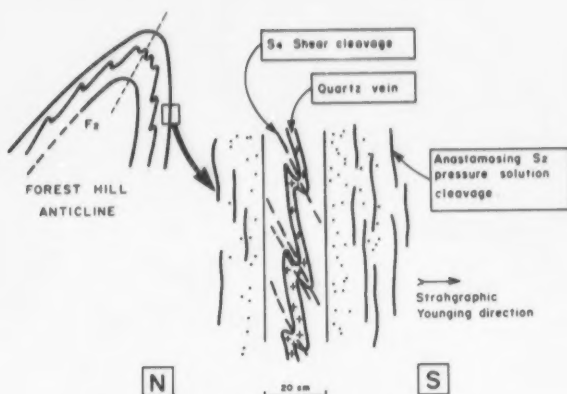


Figure 10. F_4 shear folds in strata-bound quartz vein suggesting an antiform to the south. The major regional F_2 fold axis lies to the north. Minor fold symmetry is incorrect for F_2 fold geometry. Location: 3 + 00 m west on exploration grid at Forest Hill.

GOLD MINERALIZATION

Native gold occurs both in veins and wall rocks. Tellurides are not common in the Meguma Group gold deposits although Bi and Ag tellurium complexes are common locally. Vein gold represents the bulk of historical production although recent exploration efforts at several gold districts (e.g. Moose River, Beaver Dam, Fifteen Mile Stream, Forest Hill) reveal the presence of ore grade gold associated with sulphides in wall rock over substantial mining widths (~ 30 m).

GOLD IN VEINS

Gold occurs in a number of specific sites within most quartz vein types (Table 1). These include coarse-to fine-grained nuggety native gold in pure quartz within and adjacent to vein margins such as the classical coarse

gold nuggets, as large as 11 ounces, recorded in provincial museums and

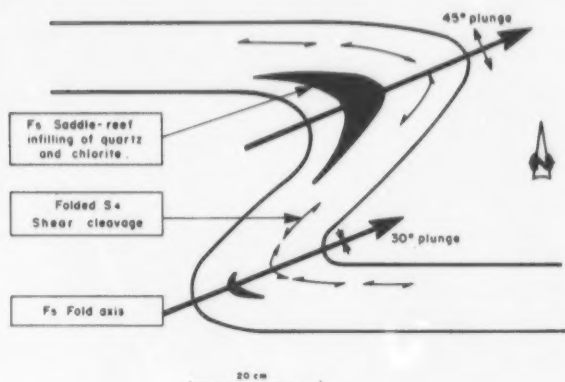


Figure 11. Simplified plan view of F_5 saddle-reef formation. Infilling is quartz and chlorite. Note folding of S_4 shear cleavage. Location: 6 + 00 m east on exploration grid at Forest Hill.

currently being extracted in underground exploration at several mining operations (Tangier, Forest Hill). However, more characteristically, gold in pure quartz (from various vein types) rarely exceeds 1 - 2 mm. Native gold is also found in a variety of other minerals within the quartz veins including plagioclase, biotite, apatite, tourmaline, amphibole and sulphide minerals (arsenopyrite, pyrrhotite, chalcopyrite, galena, sphalerite, pyrite). In these sites the gold is generally found as crosscutting fracture and vug fillings at the intersections of microfractures. Micron size gold grains (0.5-10 μm with euhedral crystal shapes occur along fluid inclusion planes which post-date recrystallized quartz grain boundaries (Fig. 12). Many of these grains are in contact with fluid in the inclusions suggesting that the fluid and gold were trapped contemporaneously. A high degree of crystallinity is typical of gold in the quartz veins. Thin wires, flattened platelets and irregular masses are also common.

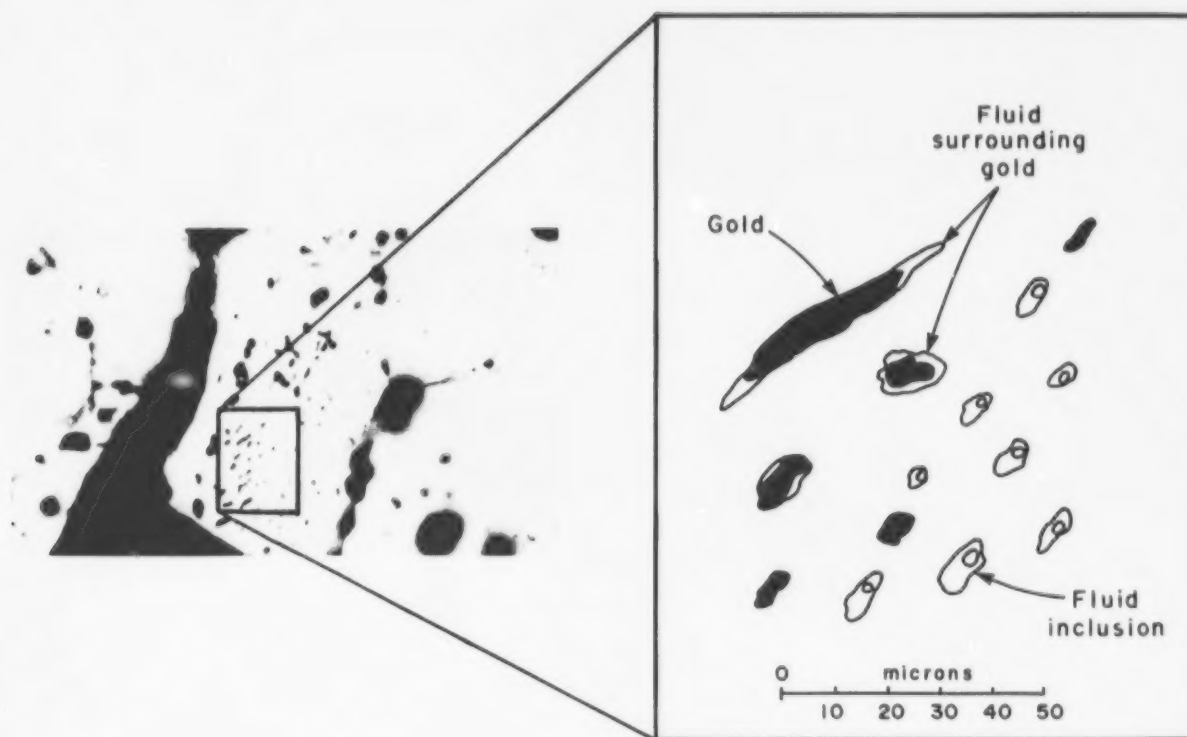


Figure 12. Micron size gold along a fluid inclusion plane. Plane crosscuts recrystallized quartz grains in folded quartz vein. Some gold is surrounded by fluid. Gold and fluid inclusions occurred contemporaneously along the same healed fracture.

GOLD IN WALL ROCK

Anomalous concentrations of gold in wall rocks can be attributed to fine grained (micron size to 1.0 mm) particles confined to small fractures in the wall rock or intimately associated with sulphides in the wall rock. These sulphides occur as stringers, disseminations and irregular masses with minor amounts of quartz. Gold occurs attached to the margins, as stringers and as disseminations throughout the sulphide minerals. Another common location for gold is along the altered fringe adjacent to vein/wall rock contacts. In this setting, gold commonly occurs along thin ac type quartz veins which crosscut earlier phyllosilicates and aluminosilicates. Locally (e.g. Cochrane Hill, Forest Hill) this gold

transects vein/wall rock boundaries. Rarely, gold occurs in altered, sericite-rich argillite in the complete absence of quartz or sulphide (e.g. Moose River, Fifteen Mile Stream) along S_4 cleavage planes.

CHEMISTRY OF GOLD

At present, gold compositions for the Cochrane Hill, Forest Hill, Dufferin and Beaver Dam gold deposit are available, although all of the other districts are currently being analyzed. Compositions for gold at the Cochrane Hill deposit (Fig. 13) show silver (2 - 10 wt. %) as the only major element associated with gold. Compositions from the other districts show a similar composition with the exception of a single grain in the centre of an arsenopyrite crystal from

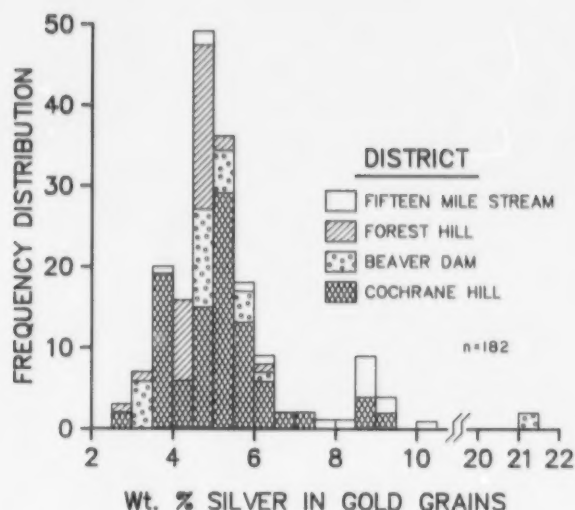


Figure 13. Histogram of weight percent silver in gold grains from 4 gold deposits in south-western Nova Scotia.

Beaver Dam which yielded two analyses with high silver contents (23.8 and 19.2 wt. % Ag).

AGE OF GOLD

Gold mineralization is intimately associated with quartz veins and alteration within the gold districts. Relative age relationships suggest that this mineralizing event is temporally associated with Devonian-Carboniferous granitoid plutonism (380 - 360 Ma) or is slightly younger (Smith, 1986b). Absolute $^{40}\text{Ar}/^{39}\text{Ar}$ age dating of muscovite and biotite from the Beaver Dam gold deposit (see *Meguma Gold Studies III*: this volume) confines the age of the mineralized veins at 370 Ma. There is no evidence to suggest that gold mineralization is older than this and subsequently remobilized. All field and laboratory data dictate that the pervasive alteration, vein emplacement, anomalous metamorphism (see *Meguma Gold Studies I*: this volume) and plutonism all occurred at approximately the same time. However

in most cases gold occupies late structural sites in deformed veins (e.g. gold crosscutting garnet porphyroblasts at vein margins). Gold grains are generally mechanically flattened by late stage D_4 and D_5 deformation (e.g. Cochrane Hill, Forest Hill, Beaver Dam). Therefore, it is concluded that the gold was deposited during and after major vein formation at 370 Ma (Fig. 2).

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MEGUMA GOLD STUDIES III

TIMING OF MINERALIZATION AT THE BEAVER DAM GOLD DEPOSIT, EASTERN MEGUMA TERRANE, NOVA SCOTIA: IMPLICATIONS FOR MEGUMA GOLD DEPOSITS¹

D. J. Kontak, P. K. Smith and P. H. Reynolds²

INTRODUCTION

The age of mineralization in Meguma Group gold vein deposits is a critical parameter which has obvious implications regarding genetic models and, more importantly, exploration. However despite the obvious importance of such information to the study of gold mineralization, no absolute time constraints are currently available. Instead, the timing of mineralization has always been inferred from structural and metamorphic relationships (e.g. Graves and Zentilli, 1982). The presence of abundant biotite, muscovite and plagioclase as integral constituents of vein paragenesis make the mineralized systems amenable to radiometric dating using the ^{40}Ar - ^{39}Ar technique. In addition, the presence of vein carbonate, chlorite, tourmaline and rare amphibole enable the Rb-Sr dating technique to be used.

Samples from the Beaver Dam gold deposit were dated using the ^{40}Ar - ^{39}Ar technique as part of a program to obtain absolute ages for as many of the gold districts as possible. Additional material from other Meguma Zone gold districts is currently being analyzed and results will be reported in the future. However, because of the

relevance of the initial results to gold exploration, data for the Beaver Dam deposit are presented and discussed now.

METAMORPHIC, STRUCTURAL AND VEIN RELATIONSHIPS AT BEAVER DAM

The Beaver Dam gold deposit is located in the eastern Meguma Terrane, immediately east of the River Lake Pluton (Fig. 1). The deposit, hosted by metasedimentary rocks of the Lower Paleozoic Goldenville Formation, occurs in steeply dipping (70 - 75° N) strata which form the southern, overturned limb of the Beaver Dam-Fifteen Mile Stream Anticline. This anticline is presumed to represent regional deformation of Late Devonian age, part of the Acadian Orogeny.

Regional metamorphic grade in the district is lower greenschist facies with biotite the dominant phyllosilicate phase. Although these conditions prevail within host rocks at the present level of mine development, a different scenario is observed a few hundred metres west where diamond-drilling (holes at 50 - 60° angles) has provided access to the unexposed stratigraphy. In this latter case, high grade metamorphic assemblages (andalusite-biotite-garnet-cordierite-

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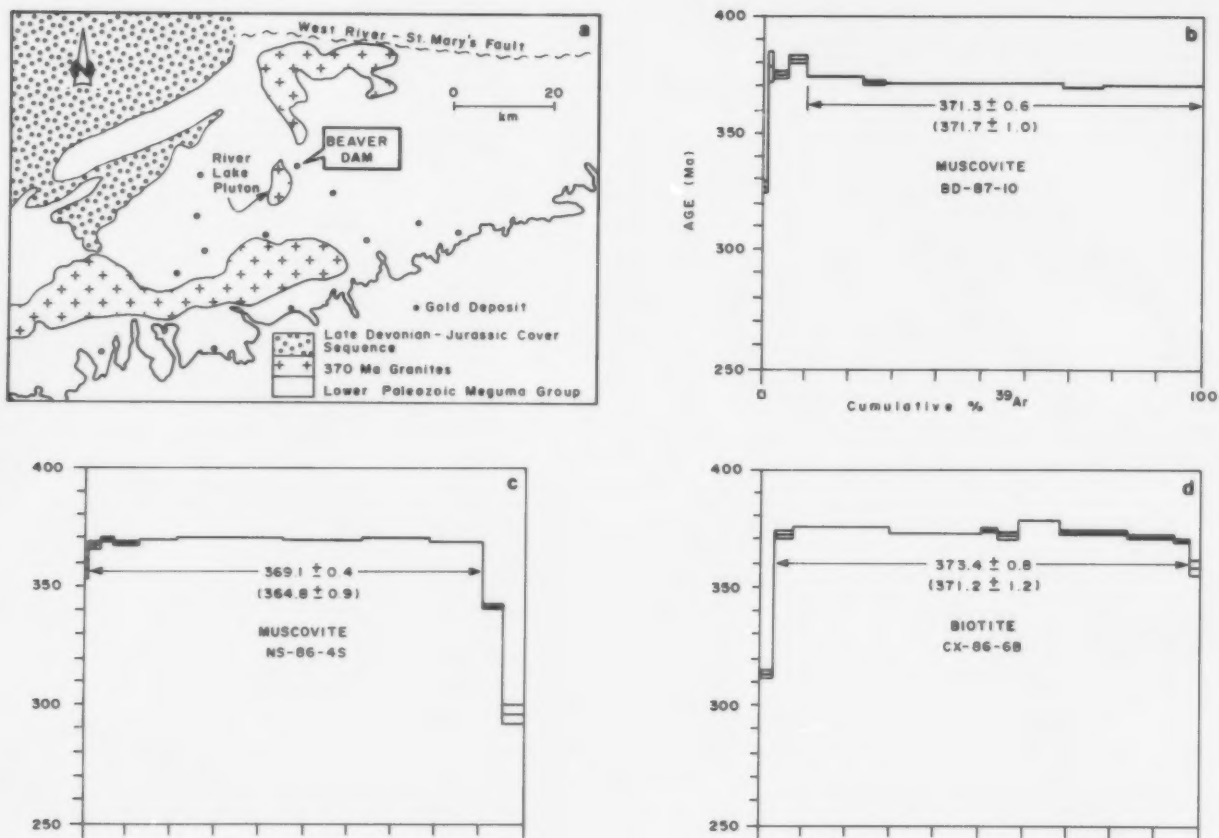


Figure 1. (a) Geological map of the eastern part of the Meguma Terrane showing distribution of the gold deposits in the Meguma Group and location of the Beaver Dam gold deposit. (b, c, d) Results of the ^{40}Ar - ^{39}Ar stepwise heating experiments for the micas dated in this study are shown plotted as a function of age versus cumulative % ^{39}Ar released for each step. The ages and 1 sigma errors indicated for each of the dated samples represent the plateau age with the total gas ages given in brackets.

staurolite) overprint the regional structural and metamorphic fabrics. Metamorphic minerals at the top of the drillholes appear as fine grained phases in pelitic lithologies, but coarsen to centimetre-size grains within 200 m down the drill core. Farther west and immediately north of the River Lake Pluton abundant pegmatite-aplite dykes occur cutting high grade metasedimentary rocks.

Abundant quartz veining and attendant wall rock alteration, notably

silicification, is developed in rocks intersected by the drill core and overprints the high grade metamorphic assemblages. Thus, veins are interpreted to post-date the metamorphic event. A similar relationship is observed between the veins and alteration and calc-silicate assemblages developed in calcareous lithologies.

The dominant structural feature in host lithologies of the Beaver Dam deposit is a penetrative fabric defined

by either pressure solution cleavage or slaty cleavage, depending on the rock type. However, this fabric is overprinted by a second cleavage which is best observed where folded quartz veins are present. In such cases, the older fabric is seen to wrap around the folded quartz veins whereas the younger fabric is axial planar to the folds. The younger fabric is interpreted to represent a shear overprint foliation similar in age to that observed, for example, along the northern boundary of the Meguma Terrane (Mawer and Williams, 1986; Mawer and White, 1987) and at other gold deposits (Smith and Kontak, 1986).

From the above relationships we infer that the quartz veins and associated alteration at the Beaver Dam deposit post-dated the local, high grade metamorphism spatially related to the River Lake Pluton. In addition, vein formation was later than regional deformation and was synchronous with the younger shear overprint deformation discussed above.

PREVIOUS GEOCHRONOLOGICAL STUDIES AND TIME CONSTRAINTS

A considerable number of geochronological studies have focused on the thermal, tectonic and magmatic history of the Meguma Terrane. Relevant to this study are the following data: (1) regional metamorphism of the Meguma Group at ca. 415 ± 10 Ma (Reynolds and Muecke, 1978; Keppie and Dallmeyer, 1987); (2) emplacement of large granitoid batholiths and satellite plutons at ca. 370-360 Ma (Clarke and Halliday, 1980; Reynolds et al., 1981, 1987; Keppie and Dallmeyer, 1987); and (3) development of heterogeneous, ductile shear overprint fabrics at 370-360 Ma along the northern boundary of the Meguma Zone (Keppie and Dallmeyer, 1987). In the immediate vicinity of the Beaver Dam deposit, Thomas (1979) reported a conventional K-Ar biotite age of 331 ± 12 Ma for the River Lake Pluton and

Krogh and Keppie (1988) recently obtained concordant zircon and monazite ages of ca. 372 Ma for this intrusion.

SAMPLES ANALYZED AND ANALYTICAL PROCEDURES

Three samples were selected for age determination; locations and geologically pertinent information are summarized below:

(1) CX-86-6B (biotite): medium grained, fresh biotite in a quartz-plagioclase-biotite vein intersected at 77.7 m depth in diamond-drill hole CX-86-6. The hole was collared just west of the Beaver Dam deposit on ground held by Coxheath Gold Holdings Ltd., but the veins are inferred to represent an extension of the same mineralized zone as observed on the Seabright Resources Ltd. property to the east.

(2) BD-87-10 (muscovite): coarse grained, fresh muscovite in a massive quartz vein containing plagioclase-muscovite-carbonate-apatite. The vein was collected from the Beaver Dam deposit at the western extension of the 1100 foot level workings as of February 19, 1987.

(3) NS-86-4S (muscovite): coarse grained, fresh muscovite from a pegmatite-aplite dyke intersected at 109 m depth in diamond-drill hole 4S-86-1 collared immediately north of the River Lake intrusion on property held by Four Season Ltd. The sample represents part of a swarm of granitic dykes cutting highly silicified and thermally metamorphosed metasedimentary rocks of the Goldenville Formation.

Pure mineral separates, prepared using conventional magnetic separation and heavy liquid techniques, were analyzed at Dalhousie University using the ^{40}Ar - ^{39}Ar incremental step-heating technique (see Faure (1977) for general review). Complete details of the experimental procedures are amply described in Reynolds et al. (1987).

ANALYTICAL RESULTS

Analytical results are shown in Figure 1 and indicate very similar age spectra for all 3 samples with plateaus of ca. 370 Ma. The plateaus in all samples are very well defined and comprise $\geq 90\%$ of the gas released in all cases. For the individual samples the following plateau ages (± 1 sigma errors) are calculated: (1) 369.1 ± 0.4 Ma for muscovite NS-86-4S (90% gas); (2) 371.3 ± 0.6 Ma for muscovite BD-87-10 (92% gas); and (3) 373.4 ± 0.8 Ma for biotite CX-86-6B (95% gas).

The 370 Ma age for muscovite NS-86-4S from north of the River Lake intrusion contrasts with a previously reported conventional K-Ar biotite age of 331 ± 12 Ma obtained by Thomas (1979) but is identical to the 372 Ma U-Pb (zircon, monazite) age of Krogh and Keppie (1988). Considering the generally uniform 370 Ma age for all other granitoid intrusions in the eastern Meguma Terrane (Reynolds et al., 1981; Keppie and Dallmeyer, 1987), the younger age is considered anomalous and may indicate a later tectono-thermal event. The concordancy of the U-Pb ages of Krogh and Keppie (1988) and the muscovite age reported here also imply rapid cooling for the River Lake intrusion since these radiogenic systems have larger differences in their respective blocking temperatures (e.g. Harrison and McDougall, 1980).

DISCUSSION

The concordancy of age data for the 3 samples examined in this study is interpreted to reflect a common thermal history. In addition, because of the essentially identical ages obtained for minerals with different blocking temperatures (250°C for biotite versus 350°C for muscovite), it is inferred that the area must have cooled rapidly. This latter point is further substantiated by the 360-370 Ma ages for biotite and muscovite from intrusions, contact metamorphic

aureoles and shear zones in the eastern Meguma Zone (Keppie and Dallmeyer, 1987; Reynolds et al., 1981).

Results of the absolute dating are both consistent with and confirm the age of the Beaver Dam deposit inferred from field relationships, as discussed previously. We emphasize that the data are not considered to reflect a later, superimposed thermal event related to granitoid emplacement for the following reasons: (1) wall rock adjacent to sample BD-87-10 does not record effects of the high temperature thermal event recorded around the River Lake intrusion; (2) the age spectra give good plateau ages for $\geq 90\%$ of released gas and show no evidence of diffusion profiles which might be suspected if a thermal overprinting event had occurred; (3) the minerals dated show no petrographic evidence of either a thermal or tectonic overprint, they are euhedral to subhedral, fresh mineral phases with a simple paragenesis. We also note that electron microprobe analyses of vein plagioclase, garnet and tourmaline indicate the presence of well developed zoning profiles. It is unlikely that such profiles would have been preserved if a thermal overprinting event had occurred; and (4) stable isotope studies do not record evidence of a later influx of fluid (see *Meguma Gold Studies V*, this volume).

Implications of the 370 Ma age for vein emplacement and presumably gold mineralization at the Beaver Dam deposit have been considered in terms of genetic models and exploration. With respect to the former, the age indicates that models which invoke a synmetamorphic origin for vein formation via release of fluids during prograde metamorphism and concomitant hydraulic fracturing (Graves and Zentilli, 1982; Mawer, 1986, 1987; Henderson and Henderson, 1986) must be reconsidered. Instead, the age data constrain formation of the auriferous veins to a time when the Meguma Terrane

had presumably cooled on a regional scale and had experienced a certain degree of uplift and denudation. The coincidence of ages reported here and generation and emplacement of large granitic batholiths (e.g. South Mountain and Musquodoboit Batholiths) within the Meguma Terrane suggest a possible connection, although perhaps more spatial than genetic. The similarity in terms of age for gold mineralization and magmatic activity is interpreted to reflect a similar process of large-scale dehydration of the lower crust ca. 370 Ma ago. It is interesting to note, therefore, that a similar relationship has been suggested, for example, in the Archean Superior Province where the ages of magmatism and gold mineralization overlap (Kerrick et al., 1984; Colvine et al., 1984; Corfu and Andrews, 1987). In fact, there is considerable data being accumulated which indicates a more than just spatial relationship between these two phenomena in Archean terranes (e.g. Hodgson, 1986; Cameron and Hattori, 1987; Hattori, 1987). Whether there also exists a direct relationship between Meguma Group gold deposits and magmatism depends on additional information which is being accumulated and will be addressed elsewhere.

The importance of these age data to exploration becomes relevant in terms of where gold mineralization may occur. Recognition of a potential temporal association of gold mineralization and granitoid intrusions opens new ground to exploration. The presence of 360-370 Ma old granitoid rocks along the entire length of the Meguma Zone suggests that this whole area is potentially favourable for gold mineralization. The age data also raise the question of whether precious metal mineralization may occur within the granites themselves. In this respect it is interesting to note the presence of elevated gold contents in the Halifax Pluton (MacDonald et al., 1987) and also in greisen zones

developed along its contact with Meguma Group metasedimentary rocks (M. A. MacDonald, personal communication, 1987). Finally, correlations have been made between the occurrence of gold mineralization and metamorphic grade such that areas which were subjected to metamorphic conditions below or near the chlorite-biotite isograd were considered the most favourable (Mawer, 1986). The age data indicate that mineralization post-dated regional metamorphism and, therefore, the grade of the host rock becomes irrelevant to selecting areas favourable for gold mineralization. The presence of gold mineralization in areas of both high grade (e.g. Forest Hill and Cochrane Hill) and low grade (e.g. Tangier, Harrigan Cove) metamorphic environments is cited to further illustrate this point.

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MEGUMA GOLD STUDIES IV: CHEMISTRY OF VEIN MINERALOGY¹

D. J. Kontak and P. K. Smith

INTRODUCTION

Veins present in Meguma Group gold deposits are characterized by, in addition to voluminous amounts of quartz, the presence of silicates, carbonates, oxides and sulphides. While the latter two have generally been discussed in previous descriptions of auriferous veins (e.g. Graves, 1976; Haynes, 1986) and the former are referred to in cursory summaries of the mineral assemblages of the veins (e.g. Table 1 of Haynes, 1986; Figure 2 of Newhouse, 1936), there is no detailed documentation of the paragenesis and chemistry of the mineralogy. Vein minerals retain important information with respect to the ambient physiochemical conditions prevailing during vein formation and, therefore, have direct bearing on the genesis of the deposits (e.g. Cameron and Carrigan, 1987; Neall and Phillips, 1987; Kishida and Kerrich, 1987). Thus, the purpose of this paper is to present the initial results of ongoing studies directed at characterizing vein mineralogy. Work to date has focused on silicates and carbonates and these data are presented; results for oxides, sulphides and native gold, currently under investigation, will be presented elsewhere. Because our detailed work has focused on the Beaver Dam deposit, much of the data collected have been compiled for material from this locality.

VEIN MINERALOGY AND PARAGENESIS

Based on both field and laboratory studies two generally distinct stages of mineral paragenesis have been recognized at several deposits. The early stage of hypogene mineralization consists of calcium-rich plagioclase, biotite and tourmaline, which is overprinted by a lower temperature assemblage of carbonate, albitic plagioclase, sphene, chlorite, muscovite, apatite, scheelite, garnet, ilmenite and euhedral pyrite. Pyrrhotite, sphalerite, anhedral pyrite, chalcopryrite and rare galena probably occur throughout the paragenetic sequence. Amphibole, andalusite and epidote are restricted to a few localities and are more likely associated with wall rock alteration than vein assemblages.

The above mineralogy is not restricted to any particular vein type, although volumetrically the silicates and carbonates are more abundant in discordant and fissure-type veins whereas sulphides, excluding euhedral pyrite, are more commonly found in concordant veins. The mineralogy is rarely disseminated evenly throughout quartz veins, instead it preferentially occurs as massive mineral clots. For example, single plagioclase clots approximately 20 cm in length and similar size chlorite clots have been observed. This mode of chlorite occurrence is restricted to

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crosscutting veins where chlorite, coexisting with carbonate, euhedral pyrite $\pm$ scheelite $\pm$ albite, occupies cavities in vuggy quartz. Oxygen isotope geothermometry on quartz-chlorite pairs indicates temperatures of about 300°C for this assemblage.

ANALYTICAL DETAILS

Mineral chemistry was obtained using the electron microprobe (Dalhousie University: plagioclase, biotite, muscovite, garnet, chlorite, tourmaline, apatite), classical wet chemical (Technical University of Nova Scotia: chlorite, plagioclase, carbonate, apatite) and inductively coupled plasma mass spectrometry (ICP-MS) (Memorial University, St. John's, Newfoundland: biotite, muscovite, apatite, plagioclase, chlorite, carbonate) techniques. Only representative analyses will be presented here but a fuller set of data is available upon request from the authors.

Mineral separates were prepared using conventional techniques (i.e. combination of magnetic separation and heavy liquids) and contamination by other mineral phases was minimal. All of the carbonates were X-rayed to check for purity. Where contamination occurs it is represented by negligible quantities of quartz. Chlorite samples may contain up to a few per cent carbonate and minor (<1-2%) amounts of white mica may occur in some of the plagioclase. All material was cleaned in an ultrasonic bath of distilled water prior to analysis.

Unless otherwise stated, all data are for material from the Beaver Dam deposit.

MINERAL CHEMISTRY

PLAGIOCLASE

Plagioclase samples (representative compositions in Table 1) from

several different veins at Beaver Dam generally cluster about two distinct populations of about An_{0-10} and An_{30-50} (Fig. 1). The K_2O contents are very low (<0.1 wt. %), in contrast to igneous plagioclase of similar Ca-rich composition (e.g. Fig. 5-13, Carmichael et al., 1974). Commonly the two compositional types occur in the same vein, as for example samples 140, 4, 167 and 169 (Fig. 1c). In such cases the more albitic plagioclase occurs as an alteration product of earlier, calcium-rich plagioclase. Although zoning appears minimal from the aforementioned data, strongly zoned grains do occur (Fig. 2), with core compositions of up to approximately An_{66} in some grains. Plagioclase of similar composition as that documented at Beaver Dam occurs at Dufferin, Harrigan Cove, Mooseland, Fifteen Mile Stream, Cochrane Hill and Forest Hill.

Trace element contents and chondrite-normalized rare earth element (REE) patterns for plagioclase of variable composition are shown in Figure 3. There is no consistent relationship between the bulk composition of plagioclase (i.e. An_5 - An_{29}) and their trace element or REE contents. As a whole, Sr and Ba are anomalously high and are more comparable to values for igneous (cf. Arniand et al., 1984) rather than hydrothermal plagioclase. The REE data are variable both in terms of absolute abundance and patterns but all contain elevated absolute Eu contents, although the magnitude of the Eu/Eu^* values vary. However, in general, the patterns differ from those typical of igneous feldspars which are distinctly fractionated with $(La/Yb)_N \gg 1$ (e.g. Muecke and Clarke, 1981; Arniand et al., 1984; Hanson, 1980). Additional REE analyses for plagioclase from other gold deposits (Dufferin and Fifteen Mile Stream) also have unfractionated patterns but with lower absolute abundances (0.1 and 1.0 chondrite normalized, respectively).

Table 1. Representative chemical analyses of vein minerals.

Mineral	Apatite			Chlorite				Biotite				Plagioclase				Tourmaline		Muscovite				
Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
SiO ₂	0.00	0.00	2.30	25.41	25.89	25.04	24.88	37.02	37.74	36.83	36.36	58.75	56.59	68.43	66.79	60.40	36.36	35.86	46.33	48.15	47.55	
TiO ₂				0.16	1.00	0.08	0.08	1.61	1.77	2.16	1.68						0.26	1.30	0.00	0.48	0.00	
Al ₂ O ₃			0.42	19.42	21.34	20.73	21.70	17.77	17.40	18.37	18.08	25.95	27.01	19.58	21.47	24.14	34.05	31.04	36.60	32.02	37.83	
Cr ₂ O ₃																						
Fe ₂ O ₃			0.21		2.82	2.62	2.65									0.61						
FeO	0.17	0.16		30.75	22.78	26.84	26.84	18.57	18.13	19.13	18.89	0.06	0.04	0.07	0.00		7.12	8.30	0.32	2.60	0.45	
MnO	0.16	0.15		0.27	0.44	0.34	0.08	0.19	0.40	0.31	0.22						0.00	0.00	0.00	0.00	0.00	
MgO			0.05	11.09	13.13	12.63	12.04	10.53	11.22	9.97	9.94						0.12	6.05	6.46	0.22	2.13	0.11
CaO	56.80	56.10	57.36	0.08	0.49	0.18	0.20	0.06	0.08	0.05	0.08	8.61	8.61	0.13	2.50	3.74	2.00	2.14	0.00	0.00	0.00	
Na ₂ O	0.08	0.07	0.6	0.00	0.04	0.04	0.08	0.03	0.04	0.02	0.04	7.14	6.34	11.34	10.42	7.34	0.58	0.71	0.36	0.75	0.46	
K ₂ O			0.20	0.03	0.01	0.01	0.14	9.31	9.22	9.70	9.51	0.10	0.11	0.04	0.08	0.52			11.08	10.13	10.72	
P ₂ O ₅	42.52	40.64	38.1		0.13	0.08	0.02									0.01						
F	2.47	3.60		0.36				0.38	0.52	0.37	0.54								0.31	0.45	0.08	
Cl	0.00	0.03		0.03				0.03	0.00	0.03	0.06								0.01	0.03	0.01	
L.O.I					11.24	11.22	11.24															

1, 2, 3 apatite (1, 2 Beaver Dam, 3 Harrigan Cove); 4, 5, 6, 7 chlorites (4, 5 Beaver Dam, 6 Mine Harbour, 7 Caribou); 8, 9, 10, 11 biotite (8 = aspy rich psammite, 9 = b.p. vein with plag-bt-chl-py, 10 = fissure vein with plag-ma-chl-bt, 11 = bt in aspy pressure shadow); 12, 13, 14, 15, 16 plagioclase (12 = An₆₀, 13 = An₅₅, 14 = An₆₅, 15 = An₁₂, 16 = An₂₉); 17, 18 tourmaline; 19, 20, 21 muscovite

Analyzed by: electron microprobe = 1, 2, 4, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21
wet chemical techniques on mineral separates = 3, 5, 6, 7, 16

Aspy = arsenopyrite, plag = plagioclase, bt = biotite, chl = chlorite, py = pyrite, ma = muscovite, b.p. = bedding parallel (vein)

BIOTITE

Biotite (representative analyses in Table 1) from Beaver Dam is chemically very uniform (e.g. Fe/Fe+Mg = 0.5 ± 0.05) regardless of mode of occurrence, with no compositional difference for vein or wall rock phases (Fig. 4a). However, in terms of Ti, there is a distinct dependence on mode of occurrence such that there is a range of Ti contents (1 - 2.5 wt. %) among the samples, but a restricted range for individual occurrences (Fig. 4b). The Ti content of biotite is dependent upon temperature, among other things (e.g. fO₂), and thus the range in concentration of this element may be due to different temperatures of crystallization. For example, using the calibration of Le Bel (1979), a temperature interval of 425-300°C is inferred for biotite crystallization (Fig. 4c). These latter temperatures are consistent with those determined using other independent geothermometers (e.g. oxygen isotope geothermometry, fluid inclusions, garnet-biotite geothermometry).

Volatile contents of the biotites are quite constant with F routinely 0.5 ± 0.1% and Cl <0.1%. These values are comparable to those reported by Taner et al. (1986) for hydrothermal biotites in auriferous veins in Quebec.

Trace element contents (ppm) for a single analysis of vein biotite are as follow: Li=183, Rb=560, Sr=5, Y=5, Cs=93, and Ba=1100. The chondrite-normalized REE pattern for this sample (Fig. 5a) is basically flat with (La/Yb)_N=1, although there is a slight enrichment of the heavy REEs (HREE).

CHLORITE

Chlorite samples (representative analyses in Table 1) show very uniform compositions regardless of occurrence. For example, chlorite occurring as replacement of plagioclase or biotite, or as large clots infilling vugs in quartz have identical compositions. Analyses of fine grained chlorite via the electron microprobe technique correspond well to bulk chemical analyses of chlorite clots, as demonstrated in Table 1. Analysis of this latter type indicates the chlorites are strongly reduced with FeO/Fe₂O₃ typically 10-16. Using the compositional nomenclature of Hey (1954; Fig. 6), these chlorite samples are termed ripidolite.

Volatile contents of chlorites are low; F is typically 0.2-0.3 wt. % and Cl <0.05 wt. %. Comparative values for chlorites from regionally metamorphosed Meguma Group sedimentary rocks are not available, thus absolute comparisons cannot be made.

PLAGIOCLASE COMPOSITIONS (Beaver Dam)

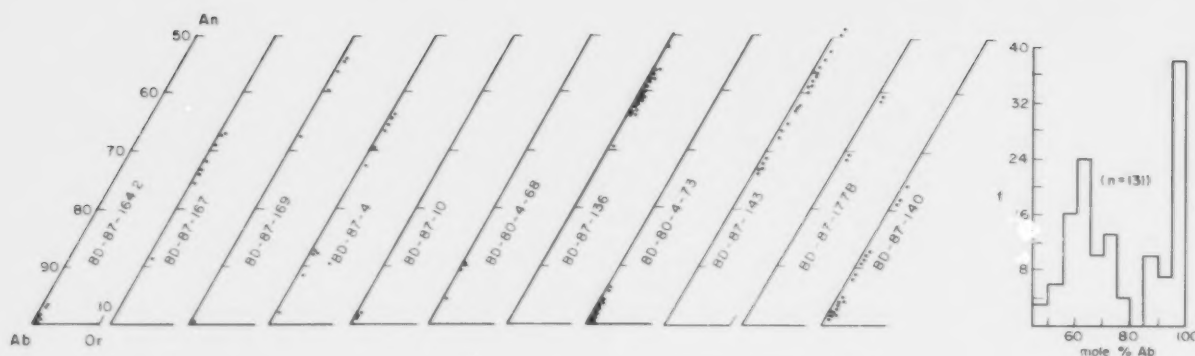


Figure 1. Electron microprobe analyses of vein plagioclase at the Beaver Dam deposit with composite histogram of all analyses.

Trace element contents (ppm) of chlorites, determined using the ICP-MS technique, are as follow: Li=80-415, Rb=<1-90, Sr=5-30, Y=2-50, Cs=<5, Ba=5-200, Pb=5-2000 and negligible Hf, Th, U, Nb and Ta. A comparable range in values for Rb, Pb and Li were obtained for chlorites using classical wet chemical techniques, which also provided data for Cr (5-70), Co (5-30), Cu (5-200), Ni (5-80), V (70-330) and Zn (200-800). The material analyzed for these latter elements represent high purity separates without sulphide inclusions (e.g. pyrite), therefore the high values for transition metals are considered quite anomalous.

REE element abundances and chondrite-normalized patterns (Fig. 7) are highly variable for chlorites despite their similar mode of occurrence (vug infillings) and major element chemistry. The strongly fractionated and light REE (LREE) enriched patterns are typical of chlorites in granitoid rocks (Arniaud et al., 1984; Alderton et al., 1980) whereas the relatively less fractionated and more depleted patterns are typical of basaltic rocks or their altered equivalents (Hanson, 1980). We emphasize the large range in these REE patterns and consider them highly

anomalous; the potential significance of this will be discussed below.

TOURMALINE

Tourmaline samples (representative analyses in Table 1) are chemically very uniform with compositions intermediate between schorl and dravite, regardless of mode of occurrence (Fig. 8). These data contrast with tourmaline compositions from Forest Hill, but are chemically similar to samples from Cochrane Hill analyzed by Reardon (1987). The narrow compositional range contrasts with the wide range documented for tourmalines in different granite-related settings in the South Mountain Batholith (SMB) (Reardon, 1987), which show a wide variation in Fe/Fe+Mg. In terms of the ternary components Na-Mg-Fe, tourmalines from Beaver Dam differ from those associated with granites in general (e.g. Slack, 1982) and those found in the SMB (Reardon, 1987) in particular.

Although the tourmalines are optically zoned, microprobe traverses across several crystals reveal only slight changes in major oxide components (Fig. 8).

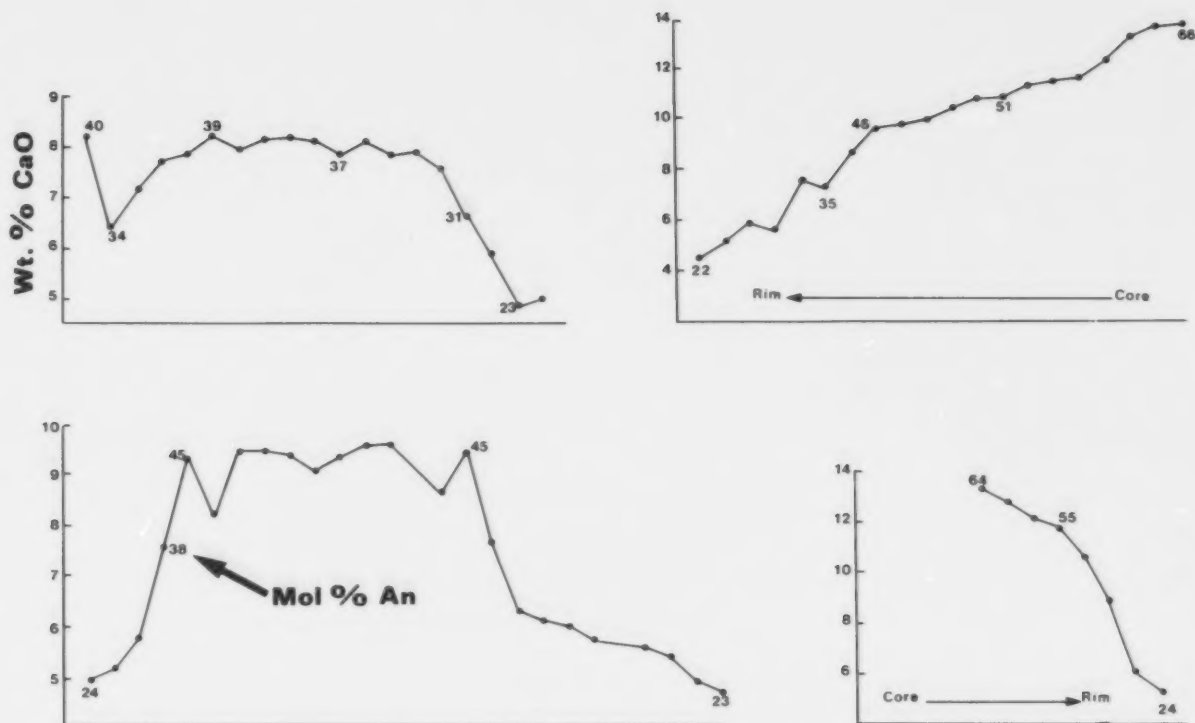


Figure 2. Profiles of vein plagioclase at the Beaver Dam deposit as determined by electron microprobe analysis. Vertical scale is wt. % CaO and numbers in parenthesis are mole % An. Profiles are rim to rim unless otherwise indicated.

MUSCOVITE

Muscovite compositions at Beaver Dam (representative analyses in Table 1) are characterized by low Fe, Mg, Ti and Na contents, thus contrasting with compositions typical of plutonic muscovite (Miller et al., 1981). In some cases where muscovite replaces chlorite, Fe and Mg contents may be relatively elevated (e.g. 2.5 wt. %). A similar relationship between mica composition and mode of occurrence has been documented by Chatterjee and Strong (1985). The analyses are similar to muscovite compositions for regional, greenschist facies metasedimentary rocks of the Meguma Group (S. Douma, personal communication, 1988).

Volatile contents of the muscovites are consistently low at

<0.2-0.3 wt. % F and <0.03 wt. % Cl. These contrast with typical values of about 1-2 wt. % F for muscovite in late stage granites of the SMB (Ham and Kontak, 1988).

Trace element contents (ppm) for muscovite (n=3) of varied occurrence (i.e. vein vs. altered wall rock) are as follow: Ba=800-1500, Rb=320-480, Li=45-80, Sr= 25-85, Nb=8, Y=3-10 and Cs=10-20. These contrast markedly with typical values for these elements in granitic rocks (granites and greisens) which are relatively enriched in Rb, Li, Cs and Nb and depleted in Ba and Sr (e.g. Ham and Kontak, 1988; Neiva, 1987).

REE concentrations are elevated compared to those typical of hydrothermal environments (i.e. greisens), especially in terms of HREE.

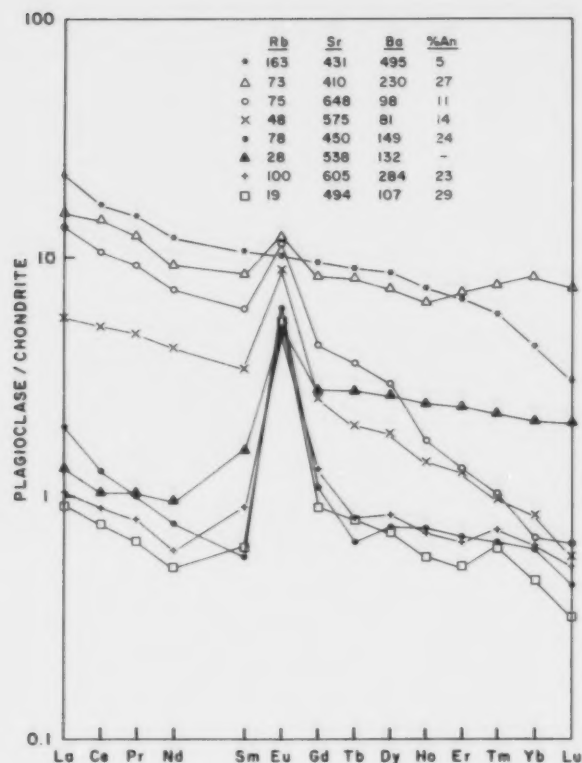


Figure 3. Chondrite-normalized REE patterns, compositions (mole % An) and trace element data for vein plagioclases from the Beaver Dam deposit.

The flat to moderately fractionated chondritic patterns (Fig. 5a) contrast with the fractionated ((La/Yb)_N=5-10) patterns obtained for most greisen-related muscovites in the SMB.

APATITE

Apatite (representative analyses in Table 1) is similar to hydrothermal vein apatite from a variety of geological environments analyzed by Roeder et al. (1987). It contains low Na, Fe and Mn, but has up to 3.6 wt. % F and very high F/Cl ratios. The F contents are similar to fluorapatites analyzed by Deer et al. (1966), most of the results in Roeder et al. (1987), and apatites in regionally metamorphosed sediments analyzed by

Yardley (1985).

An analysis of coarse (1-2 cm) apatite from Harrigan Cove (#3 in Table 1) by wet chemical techniques compares well with electron microprobe results; the high Si and Ca contents are attributed to minor amounts of quartz and calcite impurities. Trace element contents (ppm) determined on this sample were Sr = >1000, Y=650, negligible Hf, Th and U, but high total REE. The chondrite-normalized REE pattern for apatite (Fig. 5b) shows a pronounced maximum at Eu and enrichment in all middle REEs (MREE). This pattern contrasts with the less concave trends found by others for both igneous (e.g. Gromet and Silver, 1983) and hydrothermal (e.g. Roeder et al., 1987; Raimbault, 1985) apatites. However, the Eu enrichment noted here is present in some of the samples analyzed by Roeder et al. (1987).

CARBONATE

Carbonate compositions vary among deposits such that there is a provinciality. Bulk analyses of selected vein carbonates from several deposits correspond to calcite or ferroan dolomites (Fig. 9). Although carbonate type has frequently been shown to be dependant on wall rock lithology (e.g. Phillips and Brown, 1987; Kerrich and Fyfe, 1981), no such relationship has been documented for Meguma Group gold deposits. For example, the 6 analyses of calcite from Beaver Dam represent a variety of vein types cutting different lithologies.

Trace element analyses for carbonates (n=24) reveal low contents (ppm) of most elements (Ba<5, Rb<5, Pb=5-20, Li<2, and Nb and Cs are all very low), but some are consistently enriched. For example, W is 30 ± 10, and Y and Sr (Fig. 10) may be as high as 200 and 11000, respectively. Figure 10 shows a pronounced saddle shaped distribution of Y and Sr which seems striking considering that it is

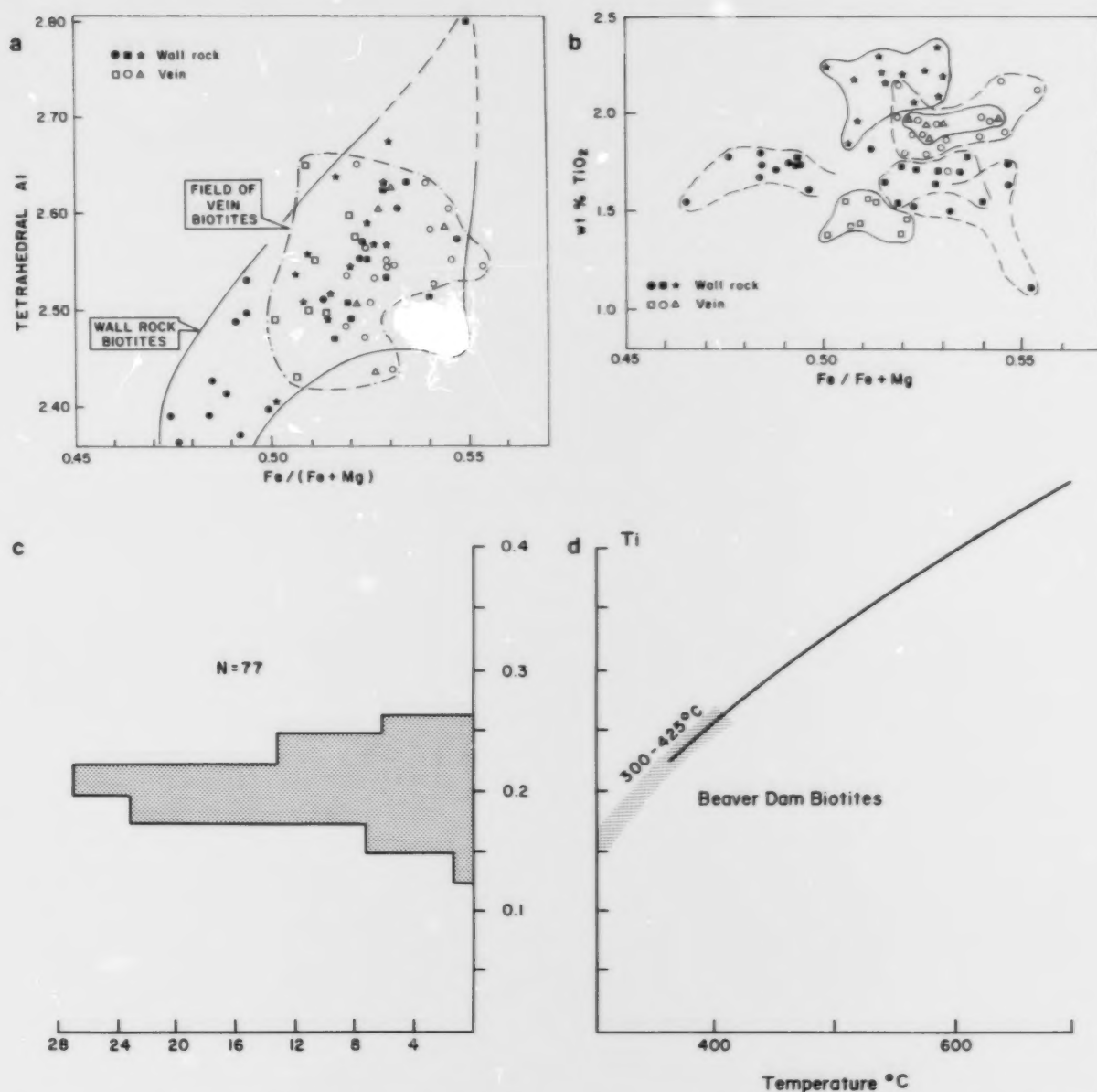


Figure 4. Composition of vein biotite at the Beaver Dam deposit as determined using the electron microprobe. (a) Tetrahedral Al versus $Fe/Fe+Mg$; (b) Wt. % TiO_2 versus $Fe/Fe+Mg$; (c) Histogram of Ti contents (cations per formula unit for 23 O) and (d) temperature diagram of Le Bel (1979).

defined by sampling 9 different gold districts. The potential significance of this will be discussed below.

Chondrite-normalized REE patterns for carbonates (Fig. 11) are variable both within and between deposits. For

example, carbonates from Beaver Dam show markedly different degrees of fractionation with both LREE and HREE enrichment/depletion and with a strong positive Eu anomaly or no anomaly. However, it is important to note that although this variability appears to

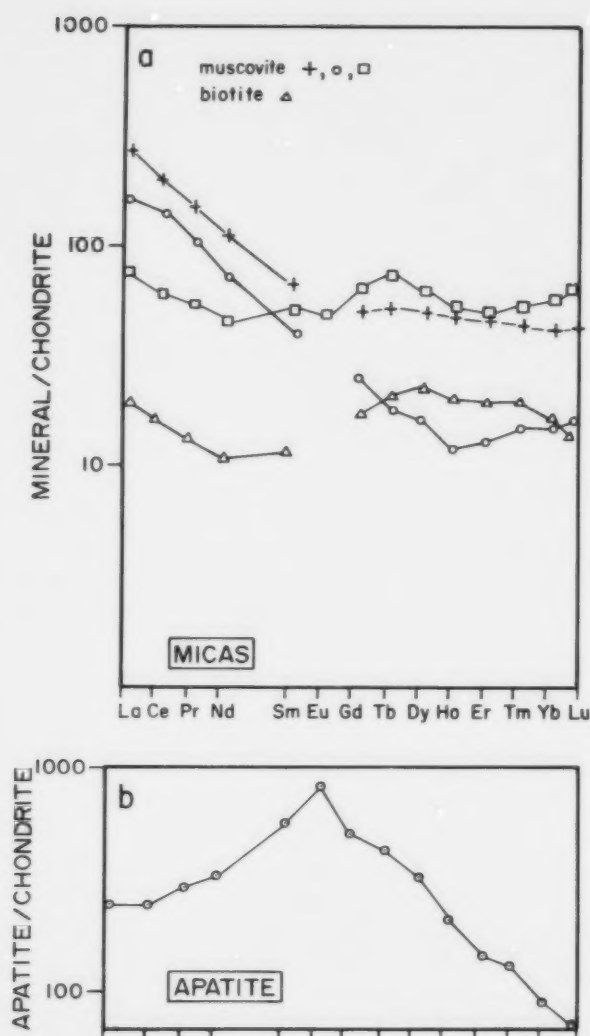


Figure 5. Chondrite-normalized REE diagrams for vein minerals. (a) Apatite from Harrigan Cove; (b) Muscovite and biotite from Beaver Dam.

characterize all the deposits, there is a consistency to the patterns such that for individual deposits the data can be grouped. For Tangier there are two obvious groups, one with HREE enrichment ($(La/Yb)_N < 1$) and a high positive Eu anomaly, and a second group with $(La/Yb)_N > 1$ and a smaller positive Eu anomaly. The significance of these data is realized when one considers that (1) the major cation contents (Ca,

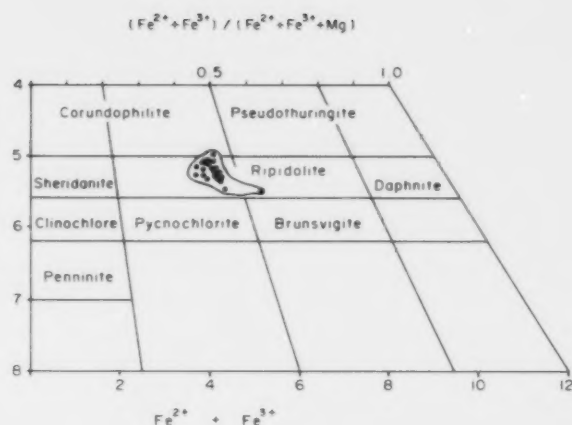


Figure 6. Electron microprobe analyses of vein chlorite from Beaver Dam in the Fe/Fe+Mg versus Si (cationic proportions) classification diagram of Hey (1954).

Fe, Mg) of the carbonates are consistent within individual deposits and (2) carbonates do not fractionate the REEs upon crystallization from hydrothermal solutions (Graf, 1983). Thus, the REE data would suggest that the chemistry of hydrothermal solutions was prone to fluctuations during mineral precipitation (see below).

GARNET

Although garnet occurs as a minor phase in several veins at Beaver Dam, chemical data are presently only available for two garnetiferous veins. While the rarity of this mineral phase may be interpreted by some to potentially indicate a xenocrystic origin, the following points indicate otherwise: (1) it is euhedral, although complexly zoned (see below), without a reaction rim; (2) garnet does not occur in the immediate wall rock and (3) its composition is unlike that of garnet in metasedimentary rocks of the Meguma Group.

Three garnet profiles are illustrated in Figure 12 and these show complex and variable compositional

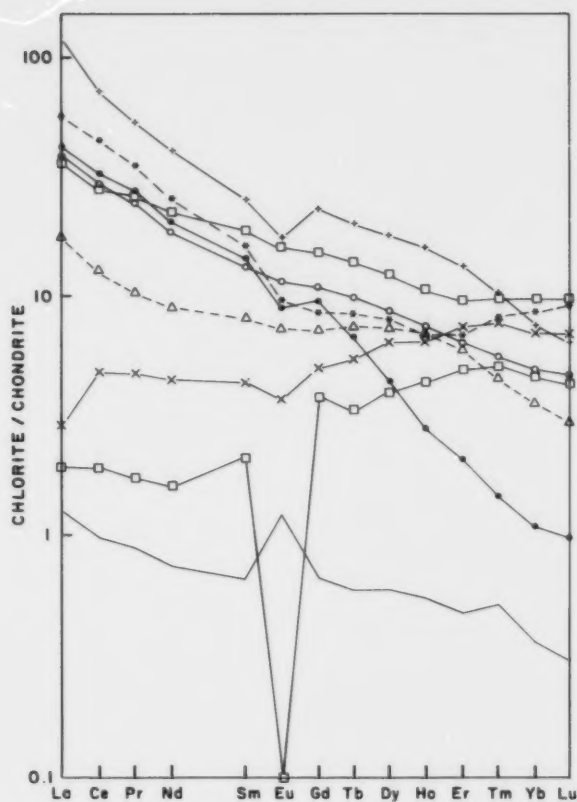


Figure 7. Chondrite-normalized REE diagram for vein chlorite from the Beaver Dam deposit.

changes. In some cases the zoning is complex with at least three distinct, symmetrically disposed, compositional zones distinguished, whereas in others a simpler, normal zoning profile is evident. The garnets are dominantly almandine-spessartine mixtures (> 90 mole % combined) with grossular the third most common component. Particularly relevant is the complex zoning profile which implies a rapidly changing fluid chemistry and conditions prerequisite for preserving such delicate zoning during garnet growth.

DISCUSSION

The data presented regarding the mineral chemistry of vein constituents within Meguma Group gold deposits indicate that there are certain

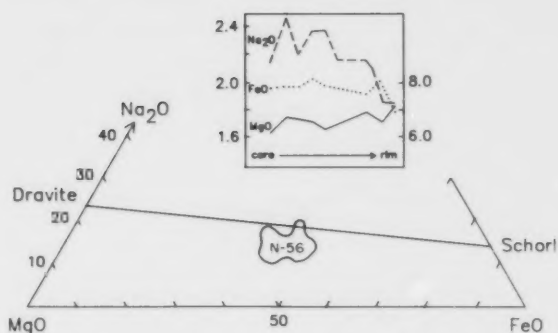


Figure 8. Electron microprobe analyses of vein tourmaline from the Beaver Dam deposit with a profile across a zoned grain also shown.

deviations from what might be expected if (1) the vein fluids represented dehydration products of Meguma Group sedimentary rocks during regional greenschist facies metamorphism and (2) the vein fluids were in equilibrium with their adjacent wall rocks. Although all the details of mineral chemistry cannot be addressed here, we focus on a few of the more significant features.

The occurrence of calcium-rich plagioclase (up to An_{66}) as an important vein constituent has important implications for fluid derivation and temperature. Since albite is the stable feldspar phase under greenschist facies conditions, it follows that the fluids must have originated from and deposited the plagioclase under higher ambient thermal conditions than this. This conclusion contrasts markedly with the generalized model of fluid derivation and vein formation during regional greenschist facies metamorphism of the Meguma Group (Graves, 1976; Graves and Zentilli, 1982), or the concept of Mawer (1986) that rocks at the chlorite-biotite isograd are most favourable for hosting gold mineralization.

The similarity in major element

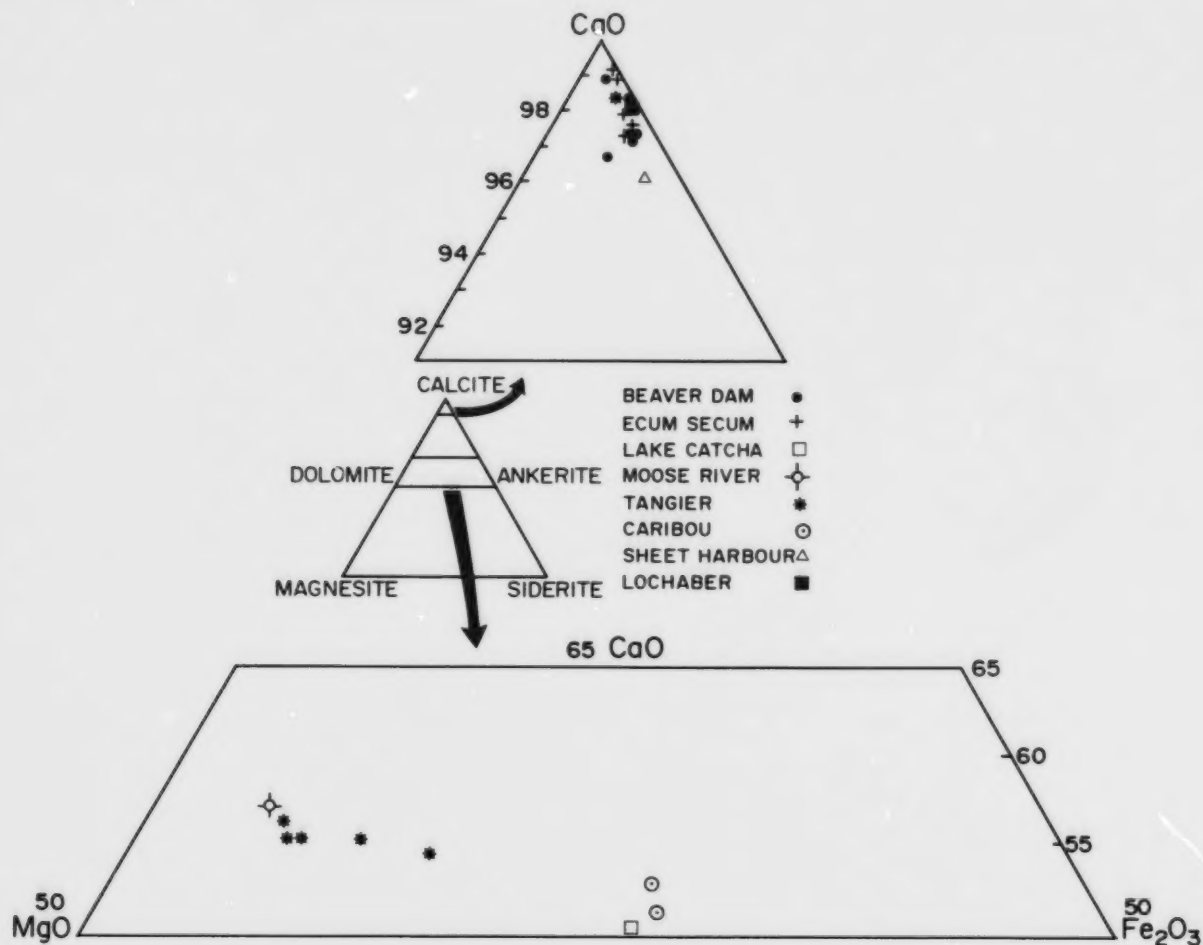


Figure 9. Compositions of carbonate from different gold districts in the Meguma Zone plotted in terms of their major cationic components.

chemistry of biotite from both veins and wall rocks is interpreted to indicate that biotite in wall rocks resulted from equilibration with hydrothermal fluids. This is in accord with the observation that extensive wall rock alteration is a feature common to all the gold districts (Smith and Kontak, 1986; Kontak and Smith, 1987).

The REE chemistry of the vein minerals, particularly carbonate, plagioclase and chlorite, indicates that vein minerals precipitated from fluids which were highly variable with

respect to absolute REE contents. This fluid variability is indicated by the fact that coexisting vein minerals exhibit similar chondritic abundances and patterns, as demonstrated for a biotite-plagioclase pair in Figure 13. The variability of REE chemistry in minerals is perhaps most pronounced for chlorites from Beaver Dam (Fig. 7) which have nearly identical major element chemistry and oxygen isotopic signatures, and occur in the same paragenetic stage. Yet there is a 100x difference in chondritic abundances and highly contrasting patterns in terms of fractionation. Less variable, but

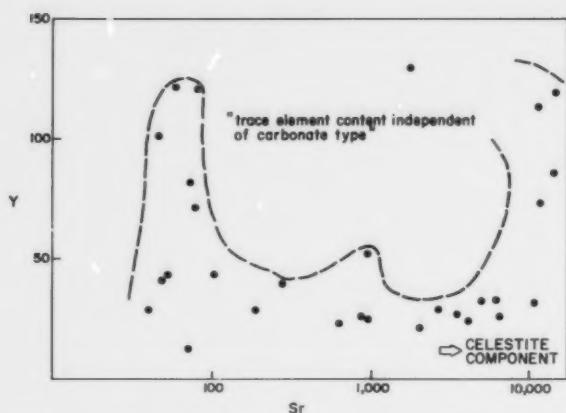


Figure 10. Binary plot of Y versus Sr for carbonates from different gold districts in the Meguma Zone.

nonetheless very different signatures are found for other vein minerals despite their similar major element chemistries. In addition, these patterns deviate markedly from the typical shale-type patterns for the immediately adjacent wall rocks at most gold deposits (our unpublished data). This contrasts with what is generally found for the minerals in question, that is they usually have REE patterns which mimic those of the host rock (e.g. greisen or vein minerals vs. unaltered host rock; unpublished data of Kontak). Thus, the highly variable REE patterns for individual mineral groups suggest that the fluids were at times quite heterogeneous during vein formation.

One mechanism which could cause the variation in REE chemistry of vein minerals involves modification of a primary, relatively homogeneous fluid via assimilation of wall rock material. Smith and Kontak (1988) present evidence to suggest that a significant amount of some veins formed as a result of replacement or extreme silicification of wall rock lithologies. Silicification would result in considerable modification of the fluid chemistry, particularly for elements that were originally in low

concentration. The primary fluid chemistry is thought to have been depleted in REEs with an unfractionated pattern since the wall rocks are enriched in REEs with strongly fractionated patterns (i.e. represent the other mixing component). Thus, it is inferred that the REE chemistry of vein minerals represents mixing of a primary hydrothermal fluid with components derived from wall rocks during alteration. Further, the primary REE signatures of the fluids are reflected by minerals with low chondrite-normalized patterns whereas the strongly fractionated and enriched patterns represent cases of extreme modification related to wall rock assimilation. The Y versus Sr plot for carbonates (Fig. 10) is similarly interpreted to reflect variable degrees of contamination of original hydrothermal fluids.

Finally, it is noted that the primary REE features inferred for the fluids contrast with both sedimentary and granitic patterns. Instead, they bear the greatest resemblance to patterns typical of intermediate to basic rocks, a fact which may have important implications for the ultimate source of the fluids.

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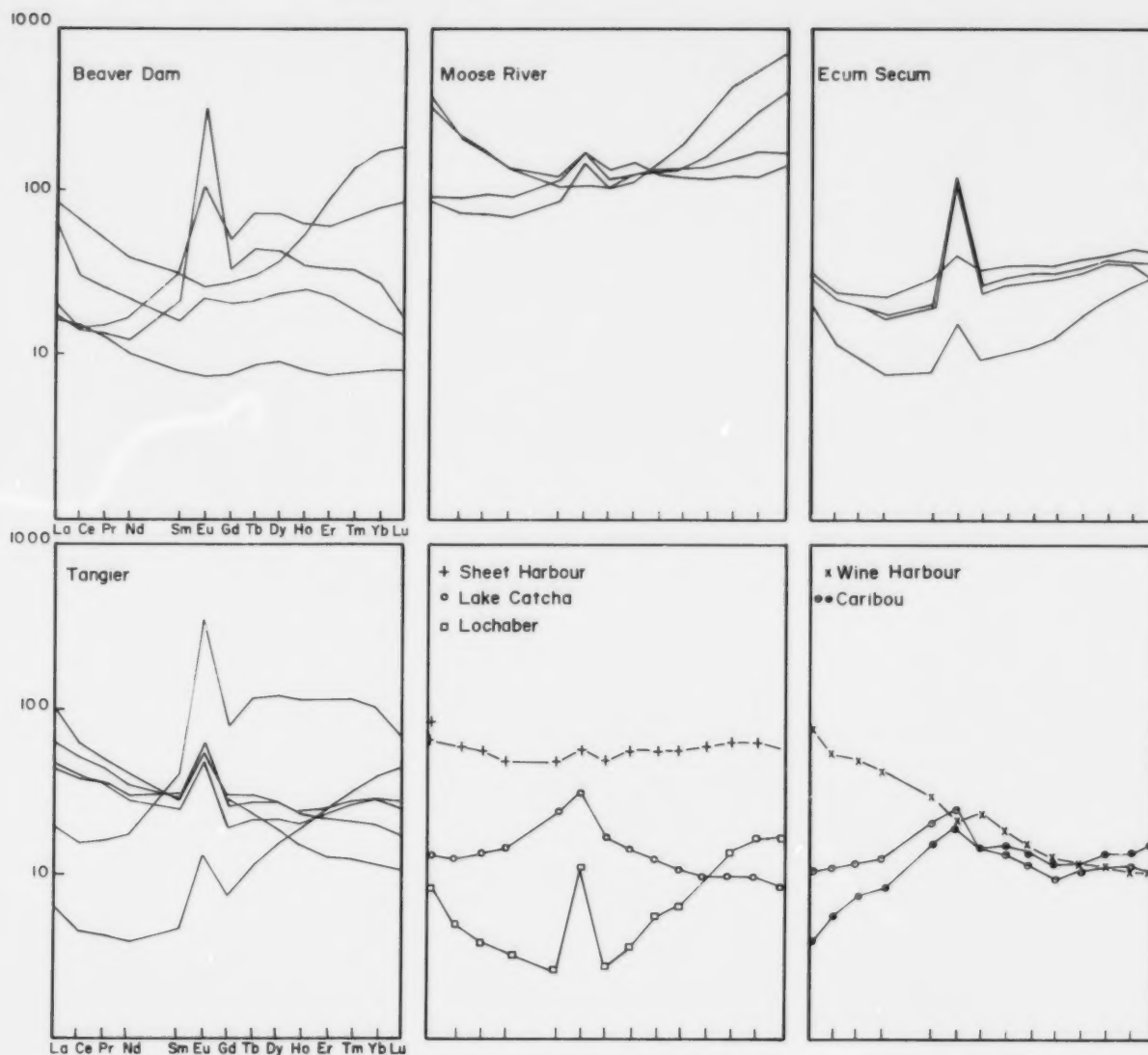


Figure 11. Chondrite-normalized REE plots for carbonates from different gold districts in the Meguma Zone.

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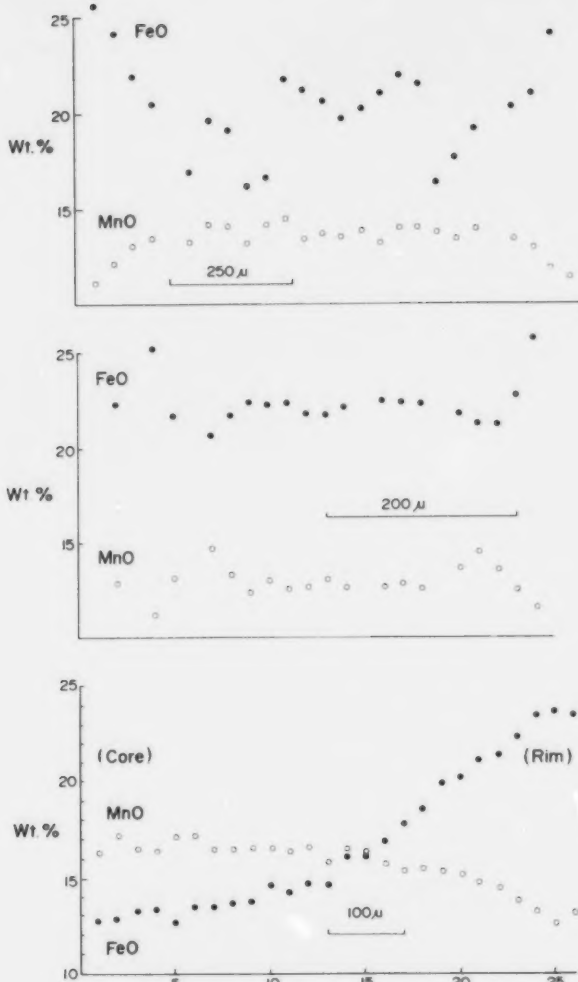


Figure 12. Compositional profiles of vein garnet from Beaver Dam as determined by electron microprobe analysis. The numbered vertical scales refer to wt. % of the adjacent oxides (same scale applies to the bottom profile). Profiles are rim to rim unless otherwise indicated.

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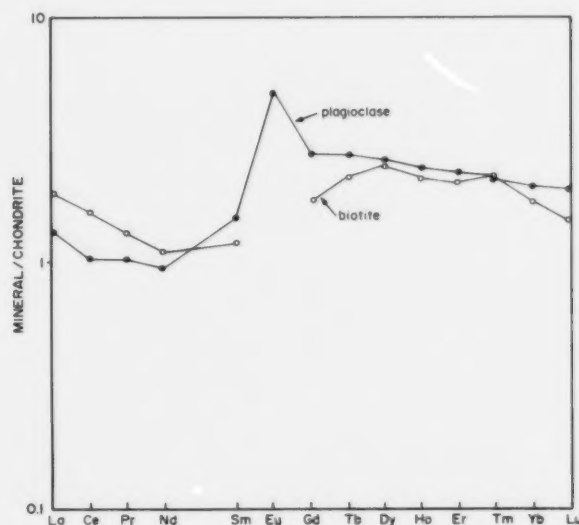


Figure 13. Chondrite-normalized REE diagram for coexisting biotite and plagioclase from a vein in the Beaver Dam deposit.

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MEGUMA GOLD STUDIES V: CARBON, STRONTIUM, OXYGEN AND SULPHUR ISOTOPIC COMPOSITIONS OF VEIN MINERALS: IMPLICATIONS FOR SOURCE RESERVOIRS AND FLUID:ROCK RATIOS ATTENDING VEIN FORMATION¹

D. J. Kontak, P. K. Smith and R. Kerrich²

INTRODUCTION

The application of isotopic analyses to ore deposit studies has proved to be of great value in fingerprinting the source of fluids, solutes and gases involved in ore-forming processes. The reason for this lies in the fact that certain physical or chemical processes fractionate the various isotopes of an element in a systematic manner such that the main reservoirs for these elements may acquire characteristic values. For example, sulphur derived from magmatic reservoirs is characterized by $\delta^{34}\text{S}$ values of 0‰/... whereas that formed by S-reducing bacteria has large negative values. Similarly, oxygen derived from magmatic reservoirs has $\delta^{18}\text{O}$ values of 5-10‰/... in contrast to generally heavier values for metasedimentary sources and lighter values where meteoric water has been involved. Hydrothermal Sr derived from basaltic rocks will be relatively non-radiogenic, in contrast to Sr leached from ancient crust or Rb-rich shales which would be radiogenic.

The application of isotopic studies to different ore deposit types has been reviewed by Ohmoto and Rye (1979), Ohmoto (1972, 1986), Rye and

Ohmoto (1974), Taylor (1987), and Sheppard (1981). With respect to gold deposits, recent investigations on numerous districts have helped to reveal potential source reservoirs for the ore fluids (e.g. Rye and Rye, 1974; Kerrich, 1987; Bohlke and Kistler, 1986; Kyser et al., 1986; Weir and Kerrich, 1987; Burrows et al., 1986; Hattori and Cameron, 1987). It should be noted, however, that in many cases the conclusions from these gold studies are quite controversial (e.g. see Kerrich, 1987, versus Burrows et al., 1986) and that isotopes can seldom be used in isolation to solve problems related to ore genesis.

It is the purpose of this paper to summarize the preliminary results of an ongoing, comprehensive study of isotopic compositions of vein minerals in Meguma Group gold deposits located in the eastern Meguma Terrane, Nova Scotia. Sulphur, carbon and oxygen data are used to infer potential source reservoirs for these elements, which have obvious implications for the source of fluids and potentially gold. Hydrogen (currently being acquired and to be reported later) and oxygen isotopes constrain the source of fluids and also the fluid:rock ratio in the systems during vein formation. Gold

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itself is monoisotopic and accordingly cannot be used as a self tracer of its source. We emphasize that in some cases the data do not offer a unique solution and that additional information will have to be acquired for some of the potential reservoirs within the Meguma Terrane before conclusions can be reached.

Details of the sampling, analytical procedures and a fuller treatment of the data will be presented in separate papers currently in preparation (e.g. Kontak and Smith, in press).

TERMINOLOGY

Values reported herein for stable isotopes (S, C, O) are quoted in terms of the notation per mil (‰), or parts per thousand. This refers to the enrichment of the sample (unknown) relative to a standard in the following manner:

$$\delta x = \frac{R_x - R_{std}}{R_{std}} \times 1000$$

Where x = unknown, R = ratio of heavy to light isotope (i.e. $^{18}\text{O}/^{16}\text{O}$), std = standard

Thus, the δ value is the difference in isotope ratio between a sample and a standard. Since the difference is generally about 1.0-0.1‰, the value is quoted as per mil (‰) for convenience. Hence, a $\delta^{18}\text{O}$ value of +10‰ means that the $^{18}\text{O}/^{16}\text{O}$ ratio of an unknown is enriched in ^{18}O by 10 per mil, or 1 per cent, relative to the standard (negative values obviously indicate depletion relative to the standard).

SULPHUR ISOTOPES

Sulphur isotopic data have been acquired for pyrite, pyrrhotite, galena and arsenopyrite from all stages of paragenesis at the Beaver Dam deposit

(n=32). In addition, arsenopyrites from an additional 7 deposits (n=13) have been analyzed to facilitate comparison between deposits. The data are summarized in Figure 1 along with analyses from Sangster (1987) for an additional four deposits, including Beaver Dam.

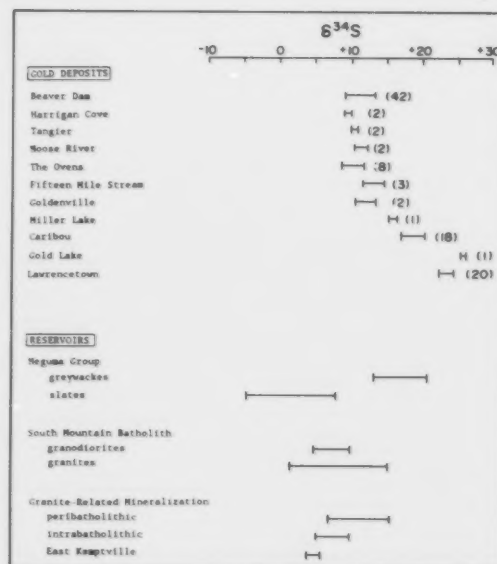


Figure 1. Sulphur isotopic data for sulphides from Meguma Group gold deposits. Number of analyses for each deposit is indicated in brackets. Data for Caribou, Ovens, Lawrencetown and Beaver Dam (n=13) are from Sangster (1987). Values for the different reservoirs are from the following sources: Meguma Group sedimentary rocks and South Mountain Batholith from Kubišius (1983); granite-related mineralization (peri- and intrabatholithic) from Chatterjee (personal communication, 1987); East Kemptville from Kontak (1987).

The results indicate a small intradeposit variation for $\delta^{34}\text{S}$ but a large range from 9-25‰ for deposits as a whole. Based on mineral

associations and wall rock alteration, which constrain pH and Eh, and temperatures of sulphide deposition, we infer that $\delta^{34}\text{S}$ (mineral) is a good approximation of $\delta^{34}\text{S}$ (fluid) (see Ohmoto and Rye, 1979). Given that variations in the composition of S in the fluid were minimal during ore formation, it follows that changes in the S isotope fractionating intensive parameters were also short lived or minimal. Consequently, S in individual deposits was derived from an isotopically uniform reservoir, whereas the composition of S reservoirs varied between deposits.

Potential reservoirs for S in the Meguma Terrane and their $\delta^{34}\text{S}$ values are shown in Figure 1 and include the large, 370 Ma old peraluminous batholiths, such as the South Mountain, and Lower Paleozoic Meguma Group lithologies. Lower crustal and mantle reservoirs should also be considered although S isotopic values for basement rocks specific to the Meguma Terrane are not known. An unmodified magmatic source is considered unlikely (see Ohmoto and Rye (1979) for discussion) but a small component cannot be eliminated entirely for deposits with low $\delta^{34}\text{S}$ values. The Meguma Group greywackes of the Goldenville Formation appear to have the appropriate range in values if a small contribution of ^{34}S -enriched S from slate is included. Thus, a tentative model involving contamination of a sulphur deficient fluid (implied by the abundance of Fe silicate phases in the veins) by Meguma Group lithologies is proposed to account for the observed range in the data.

STRONTIUM ISOTOPIC RATIOS

Strontium isotopic ratios have been determined for vein carbonates from 10 gold districts (Fig. 2). Trace element studies of vein carbonates indicate that these phases are characterized by very low Rb/Sr ratios (i.e. <0.01), thus the measured

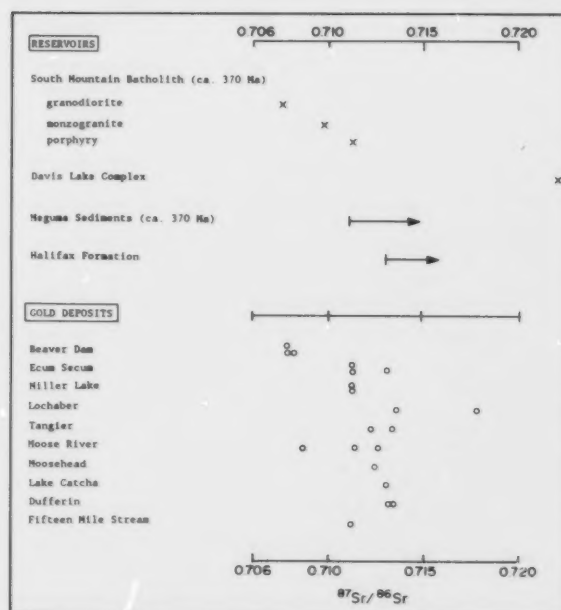


Figure 2. Strontium isotopic data for carbonates from Meguma Group gold deposits. Values for the different reservoirs are from the following sources: South Mountain Batholith (Clarke and Halliday, 1981); Davis Lake Complex (Richardson et al., 1987); Meguma Group Sediments (Clarke and Halliday, 1981) and Halifax Formation (Lambert et al., 1984).

$^{87}\text{Sr}/^{86}\text{Sr}$ ratios are considered to closely approximate their initial ratios (Sr_i) (i.e. little modification of Sr_i due to decay of ^{87}Rb to ^{87}Sr) and that of the fluid from which the carbonates precipitated. Collectively the isotopic ratios range from a minimum of 0.7079 for Beaver Dam (n=3) to a maximum of 0.7156 for Lochaber (n=2), with most of the results (n=20) averaging 0.7120 ± 0.001 . Although there is general conformity of Sr isotope data within a single deposit, some variation occurs which may be interpreted in terms of possible mixing of Sr from different sources (i.e. fluid and wall rock). There is no correlation of the Sr_i values with

proximity to granites, geographic distribution or nature of occurrence within deposits (e.g. carbonate chemistry or wall rock).

Data for the gold deposits are compared to potential source reservoirs in Figure 2, including granitoids of the 370 Ma old South Mountain Batholith and ca. 330 Ma old Davis Lake Complex, and Lower Paleozoic Meguma Group lithologies. Collectively, the Sr_i values of carbonates do not correspond to a single source identified in Figure 2, but instead they overlap the fields defined for granites and sediments. The range of data may possibly reflect a fluid initially characterized by a low Sr_i value as detected, for example, at the Beaver Dam deposit, contaminated to variable degrees with more radiogenic Sr. The range of data within some deposits may similarly be explained by a fluid-wall rock reservoir mixing model. However, regardless of the reason for the spread of Sr_i values, the present data strongly suggest that a source component less radiogenic than the Meguma Group must be involved.

OXYGEN ISOTOPES

SILICATES

Oxygen isotopic measurements have been conducted on silicate mineral phases from the Beaver Dam (quartz, plagioclase, chlorite) and Tangier (quartz) deposits. Data for the Beaver Dam deposit is exceptionally uniform with the following mineral $\delta^{18}O$ values: quartz = 13.4 ± 0.9 (n=17), plagioclase = 12.2 ± 0.7 (n=7) and chlorite = 6.2 ± 0.6 (n=6). The minerals analyzed represent a wide variation in vein types (e.g. concordant, crosscutting, ac), paragenesis, morphology and immediate wall rock composition, thus, the uniformity of the data is striking.

Several quartz-chlorite pairs (n=6) in late vug infillings ($\pm$ pyrite $\pm$ albite $\pm$ carbonate $\pm$ scheelite) in

fissure and crosscutting vein types indicate temperatures of ca. 300°C, consistent with chlorite-feldspar pairs (n=2) and preliminarily fluid inclusion thermometric determinations. These temperatures provide a minimum for vein emplacement that is independent of pressure corrections as would apply to the fluid inclusion homogenization data.

A cursory survey of quartz from the Tangier deposit indicates similar $\delta^{18}O$ values (14.2 ± 0.1 , n=3) as were obtained on quartz at Beaver Dam. Again, although different vein types hosted by a variety of wall rock lithologies are represented, no variation in the $\delta^{18}O$ of quartz is noted.

The $\delta^{18}O$ of the hydrothermal fluid can be estimated using measured isotopic values of the minerals, mineral-water fractionation equations, and assuming temperatures of vein formation (Fig. 3; see Kyser (1987) for review). Values for the fluid, calculated for limiting temperatures of 300-400°C, are estimated at 7-11‰ for Beaver Dam and 8-11‰ for Tangier.

CARBONATES

Oxygen isotopic compositions of 53 carbonate samples from 12 gold districts are summarized in Figure 4. In general the averages for the districts range from 11.5 - 18‰ but excursions to higher values occur. For example, at Beaver Dam, Tangier and Moose River individual analyses of 22-25‰ are recorded, but these fall well above the norm. The variation in isotopic composition shows no consistent relationship with carbonate type, paragenesis or any other parameter. As with the silicate phases, the $\delta^{18}O$ value of the fluids from which the carbonates precipitated can be calculated. For a temperature of 350-250°C the mean values range from

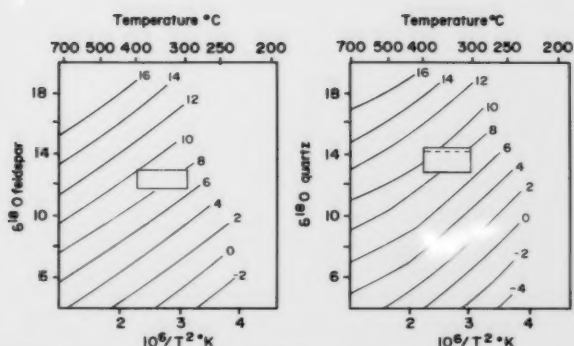


Figure 3. $\delta^{18}\text{O}$ feldspar and quartz versus temperature plots showing oxygen isotope data (mean $\pm$ one standard deviation) for feldspar and quartz from the Beaver Dam and Tangier gold deposits (Tangier is represented by the dashed line in the quartz diagram only). The family of lines represents the $\delta^{18}\text{O}$ of H_2O in equilibrium with feldspar and quartz at given $\delta^{18}\text{O}$ for specific temperatures.

7-15, with 7-12 encompassing all but a few of the more anomalous samples.

RESERVOIRS

The oxygen isotopic compositions of fluids which were involved in the generation of gold veins have been estimated at ca. 7-11‰. This range overlaps the fields defined for magmatic and metamorphic fluids in general (Sheppard, 1981; Taylor, 1979) and, therefore, without independent criteria (e.g. hydrogen isotopes) a definitive conclusion is not presently possible. Specifically for the Meguma Zone, Kontak et al. (1988) have calculated $\delta^{18}\text{O}$ values of 7-10‰ for late stage fluids derived from and in equilibrium with granites of the South Mountain Batholith, while Chatterjee et al. (1985) have documented the involvement of ^{18}O -enriched fluids in the generation of the Millet Brook uranium deposit, and Kontak

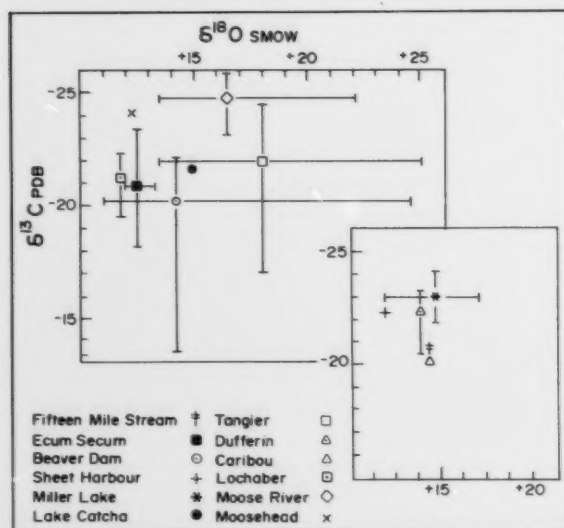


Figure 4. Plot of oxygen and carbon isotopic compositions of carbonates from Meguma Group gold deposits. The mean values and the range are indicated for individual deposits; symbols present without bars represent a single analysis.

(unpublished data) determined the ^{18}O values of the mineralizing fluids at the East Kemptville tin-base metal deposit to have been 6-8‰. Calculation of the $\delta^{18}\text{O}$ fluid in equilibrium with Meguma Group lithologies at 350-450°C using the whole-rock data of Longstaffe et al. (1980) gives values of 7-11‰. Thus, this latter reservoir is compatible with most, although not all, of the oxygen isotopic data. Again, as with the S isotope data, a certain component of magmatic fluid cannot be eliminated solely on the basis of the oxygen isotopes, but the dispersion of S, C and Sr isotope results rules out an exclusively magmatic reservoir given that regimes are generally isotopically uniform.

CARBON ISOTOPES

Carbon isotopic data have been acquired for the same carbonate samples

as analyzed for oxygen. The majority of data (Fig. 4) fall in the narrow range of -20 to -24‰ , except for a small number of samples from Beaver Dam and Tangier which have slightly less depleted values (≤ -13 and ≤ -17 , respectively). These excursions are not related to different carbonate phases since isotopic fractionation between coexisting carbonate species under hydrothermal conditions is small (Kyser, 1987), but probably reflect local changes in ambient Eh and pH conditions (Rye and Ohmoto, 1974). From mineralogical constraints on Eh and pH, the ambient fO_2 conditions remained above the CO_2 - CH_4 buffer during the deposition of carbonate. Accordingly, CO_2 was the dominant C species and the presence of a separate CO_2 phase in fluid inclusions corroborates these assumptions. Where the Eh of hydrothermal fluids is above the CO_2 - CH_4 buffer, $\delta^{13}C_{\text{mineral}} = \delta^{13}C_{\text{fluid}}$, such that the C isotopic composition of the vein carbonates signifies a ^{13}C depleted source.

The $\delta^{13}C$ values for the carbonates suggest a reduced metasedimentary source of organic carbon given that reduced organic C is the only source of ^{13}C depleted carbon. Hydrothermal CO_2 was likely derived via thermal decarboxylation, hydrolysis, or oxidation of reduced C in the source, or mixtures of these processes. Contributions from magmatic reservoirs ($-5 \pm 2\text{‰}$) or marine carbonates ($0 \pm 4\text{‰}$) can probably be excluded (Ohmoto and Rye, 1979). The fairly uniform values for the data suggest a large, moderately homogeneous reservoir, but the absence of data for possible protoliths within the Meguma Terrane or lower crust do not permit a unique interpretation of likely reservoirs at present. We note, however, that organic carbon has been documented as a component of Meguma Group lithologies within the Goldenville Formation in gold districts, and also in xenoliths of probable non Meguma Group protolith found in mafic dykes cutting the Meguma

Group (Giles and Chatterjee, 1987a).

DISCUSSION

The isotopic data can collectively be interpreted to place some constraints on the potential source regions for the fluids, gases and their constituent metals. In addition, isotopes provide information on the ambient chemical conditions of the fluids (i.e. intensive parameters) and the role of wall rock in vein formation.

Potential source reservoirs within the Meguma Terrane have been discussed previously and include the Meguma Group, the Late Devonian-Early Carboniferous granitoids, and the lower crust and upper mantle. The majority of isotopic data are consistent with a metamorphogenic origin for fluids and their constituents, while precluding a wholly magmatic source. However, while the data do not negate an involvement of Meguma Group lithologies, the extent of their contribution remains unknown. For example, the Sr_i values of vein carbonates fall below the presently identified range for the Meguma Group at ca. 360 Ma (inferred age of mineralization; see *Meguma Gold Studies III*, this volume). In addition, some of the higher $\delta^{18}O$ values calculated for vein fluids fall outside the range for Meguma-derived waters, while a source of organic carbon with ^{13}C values of ca. -35‰ remains to be identified (assuming fractionation of ^{13}C into CO_2 during hydrolysis of carbon; Ohmoto and Rye, 1979). Thus, at present, the potential involvement of a source other than the Meguma Group, perhaps a deeper basement with characteristics of the gneisses identified in the Liscomb Complex (Giles and Chatterjee, 1987b) or xenoliths described from the Tangier Dyke (Giles and Chatterjee, 1987a), remains open.

The consistency of isotopic data for a variety of minerals within

deposits, regardless of paragenesis, vein type or immediate wall rock lithology, is interpreted to reflect high fluid:rock ratios. This precludes intermittent variation in intensive parameters, particularly Eh and pH, which would have pronounced effects on isotopic fractionation between hydrothermal fluids and minerals (e.g. Ohmoto, 1972; Rye and Ohmoto, 1974; Ohmoto and Rye, 1979). These conclusions are wholly consistent with the presence of extensive alteration within the deposits (Kontak and Smith, 1987) and the conclusions based on vein and wall rock mineral chemistry for the deposits (see *Meguma Gold Studies IV*, this volume).

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MEGUMA GOLD STUDIES VI: AN INTEGRATED MODEL FOR THE GENESIS OF MEGUMA-HOSTED LODE GOLD DEPOSITS¹

D. J. Kontak and P. K. Smith

INTRODUCTION

During the past century there have been numerous theories advanced to account for the genesis of Meguma-hosted lode gold deposits. Perhaps the most widely accepted and frequently referred to is the saddle-reef model, first proposed by Faribault (1899) and based on his thorough documentation of the distribution of auriferous quartz veins within gold districts. Alternative ideas reflect the general thinking prevailing within the geological community as a whole at the time of proposal. For example, the relationship to magmatic processes suggested by Rickard (1912) and Newhouse (1936) is consistent with the early 20th century concepts of Lindgren, while the metamorphogenic-lateral secretion theory of Graves (1976) and Graves and Zentilli (1982) is similar to the model of Henley et al. (1976) and Patterson (1982, 1986) for the Otago gold fields of New Zealand. More recently, Haynes (1986, 1987) presented an exhalative model which is based on concepts suggested for various Archean gold deposits (e.g. Kerrich and Fryer, 1979) and active geothermal systems (Weissberg et al., 1979), and Sangster (1987) has made analogies to exhalative Pb-Zn mineralization found in anoxic shales of the Selwyn Basin, Yukon Territories (Goodfellow, 1987; Goodfellow and Jonasson, 1984).

In recent years there has been a resurgence in the study of gold

deposits and a variety of techniques have been used to ascertain the genesis of mineralization. Perhaps one of the better examples of this has been the work of Colvine et al. (1984) which focused on Archean lode gold deposits of the Superior Province, Ontario. In this exemplary work the authors integrated field-related studies involving structural and metamorphic investigations with laboratory studies including absolute dating, stable isotope analyses, fluid inclusion measurement and whole rock geochemistry. Most recently there have been additional studies of similar nature (e.g. Bohlke and Kistler, 1986; Neall and Phillips, 1987; Boulter et al., 1987; Robert and Brown, 1986) which indicate that integrated studies are required in order to resolve the problem of ore genesis. A similar approach has been adopted for examination of Meguma-hosted lode gold deposits and the preliminary results have been reviewed in the preceeding series of papers, which complement additional work presented elsewhere (Kontak and Smith, 1987; Smith and Kontak, 1986, 1987, 1988). In this paper we present a synthesis of these data in the form of an integrated model which is consistent with the observations and data collected to date.

DEVELOPMENT OF A MODEL FOR MEGUMA GOLD DEPOSITS

From the preceding papers there are certain important features of the

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

gold deposits which must be accommodated by any model.

(1) The deposits are localized in areas of high strain which correspond in many cases to steep, overturned limbs of early F_2 folds of presumed Acadian age.

(2) The veins and host rock lithologies have been intensely deformed due to shear overprinting by a D_4 structural event during and(or) after emplacement of the 370 Ma old granitoid suites within the Meguma Terrane. Kinematic analysis of these structures within gold districts are preliminary in nature but consistently indicate that the movement was predominantly dip slip with lesser amounts of dextral, strike slip movement.

(3) Many, but not all, gold districts are localized in areas which record the growth of coarse, randomly oriented porphyroblasts of biotite, andalusite, garnet, cordierite and staurolite. These minerals post-date regional metamorphism and deformation and were roughly contemporaneous with D_4 shearing and granite emplacement.

(4) Absolute dating ($^{40}\text{Ar}/^{39}\text{Ar}$) of one of the more significant gold districts (i.e. Beaver Dam) indicates a 370 Ma age for the mineralizing event. This corroborates earlier estimates based on the timing of vein-related alteration with porphyroblast growth and D_4 fabrics.

(5) Extensive alteration is present within all deposits examined. Most pervasive and prevalent is silicification, but phyllic, carbonate and sulphide types also occur. The "crack-seal" texture present in many veins is considered to represent examples of extreme wall rock alteration (Smith and Kontak, 1988), in contrast to an origin related to hydraulic fracturing due to synmetamorphic dehydration and

overpressuring within a sedimentary pile (Graves, 1976; Graves and Zentilli, 1982; Mawer, 1986, 1987; Henderson and Henderson, 1986).

(6) The environment of mineralization was characterized by large fluid:rock ratios as indicated by extensive alteration, similarity of vein and wall rock mineral chemistry, and similarity of stable isotopic compositions for sulphides and silicates regardless of paragenesis or mode of occurrence.

(7) The presence of an early hypogene mineral assemblage of plagioclase (An_{30-70})-biotite-tourmaline indicates initially high temperatures (probably $>450^\circ\text{C}$) for vein formation.

(8) Stable isotopic analyses exclude unmodified magmatic fluids as the dominant fluid within the systems. Instead, a metamorphic-derived fluid that has been contaminated by variable degrees of interaction with Meguma Group lithologies is considered to have been the transporting agent for gold.

(9) The source regime of the fluid is probably deep crustal, non-Meguma Group in nature and was characterized by the presence of reduced carbon, oxidized sulphur, initial Sr values <0.708 , and had the capacity to generate fluids with ^{18}O of $7-10\text{‰}$. REE chemistry of vein minerals suggests that the source region consisted in part or whole of rocks intermediate to basic in composition.

The above features of the gold deposits are not wholly consistent with most, if not all, of the previous models suggested for generation of the mineralization. Most important is evidence which indicates that the mineralizing fluids were focused into active shear zones during regional intrusion of large granitoid batholiths. A similar relationship between fluid emplacement and ambient stress regimes during formation of gold veins has been discussed by several

workers (e.g. Kerrich and Allison, 1978; Poulsen, 1986; Boulter et al., 1987; Robert and Brown, 1986) and Hodgson (1986) has stressed the importance of timing of granitoid intrusion and gold mineralization during formation of the Abitibi gold deposits.

THE MODEL

The data presented in *Meguma Gold Studies I-V* have been synthesized into a comprehensive model for the origin of the Meguma gold deposits. We emphasize that models are designed in part to provide direction for future studies and also to be tested. As work continues we expect to find inconsistencies in the model presented here, but hope that the generalities may prove useful to both the exploration and academic communities in directing their efforts at these deposits.

In Figure 1 the salient aspects of this genetic model are portrayed in a schematic fashion. The important factors are structure, heat and fluids, precisely the things which Fyfe and Henley (1973) identify as the general requirements for the formation of a large scale hydrothermal ore deposit. We consider that the Meguma deposits were generated during a single metallogenic event at ca. 370 Ma coincident with development of several necessary factors prerequisite for the formation of gold deposits, as summarized above. At this time the basal part of the crust underwent large scale dehydration as a result of thermal perturbations due to ponding of basaltic material at or near the mantle-crust boundary. The basic material is represented today in the form of mafic intrusions in the Liscomb Complex (Giles and Chatterjee, 1987) and mafic dykes along the eastern shore of the province (Ruffman and Greenough, 1988). In addition to generating the large volumes of granitic material now preserved in the form of batholiths

(i.e. South Mountain, Musquodoboit), this phenomenon also resulted in generating fluids, which were ultimately focused into favourable structures within the upper part of the crust. Thus, the fluids are envisaged as being of metamorphogenic origin and exotic to the Meguma Group, as are the metals for the most part.

The occurrence of gold deposits along certain domal structures is not coincidental, but in fact a result of focusing of fluids along semi-continuous structures. Similar concentrations of gold deposits are found in other gold provinces. For example, the importance of such structures in the localization of gold deposits is obvious in the case of the Mother Lode Belt of California (see Fig. 1 of Bohlke and Kistler, 1986) and the Destor-Porcupine Fault and Cadillac-Larder Break in the Abitibi belt of Ontario-Quebec (see Fig. 1 of Borland, 1987). Thus, we suspect that major breaks of crustal magnitude (i.e. penetrative into the ductile infrastructure) localized the gold mineralization and were first developed during the Acadian deformation event, if not earlier in some cases.

The role of granitoid rocks is important with respect to providing a mechanism to reactivate the pre-existing structures discussed above. Input of large volumes of sialic material into the crust probably resulted in large scale isostatic adjustments, thus accounting for the overall dip-slip component during the D₄ deformational event, observed in many of the gold districts. Hodgson (1986) also cited the role of granitoids in the Abitibi belt as mainly structural. However, recently several workers (Cameron and Carrigan, 1987; Cameron and Hattori, 1987; Hattori, 1987; Burrows and Spooner, 1987; Burrows et al., 1986) have interpreted the role of Archean intrusions as also being important in terms of contributing to the ore

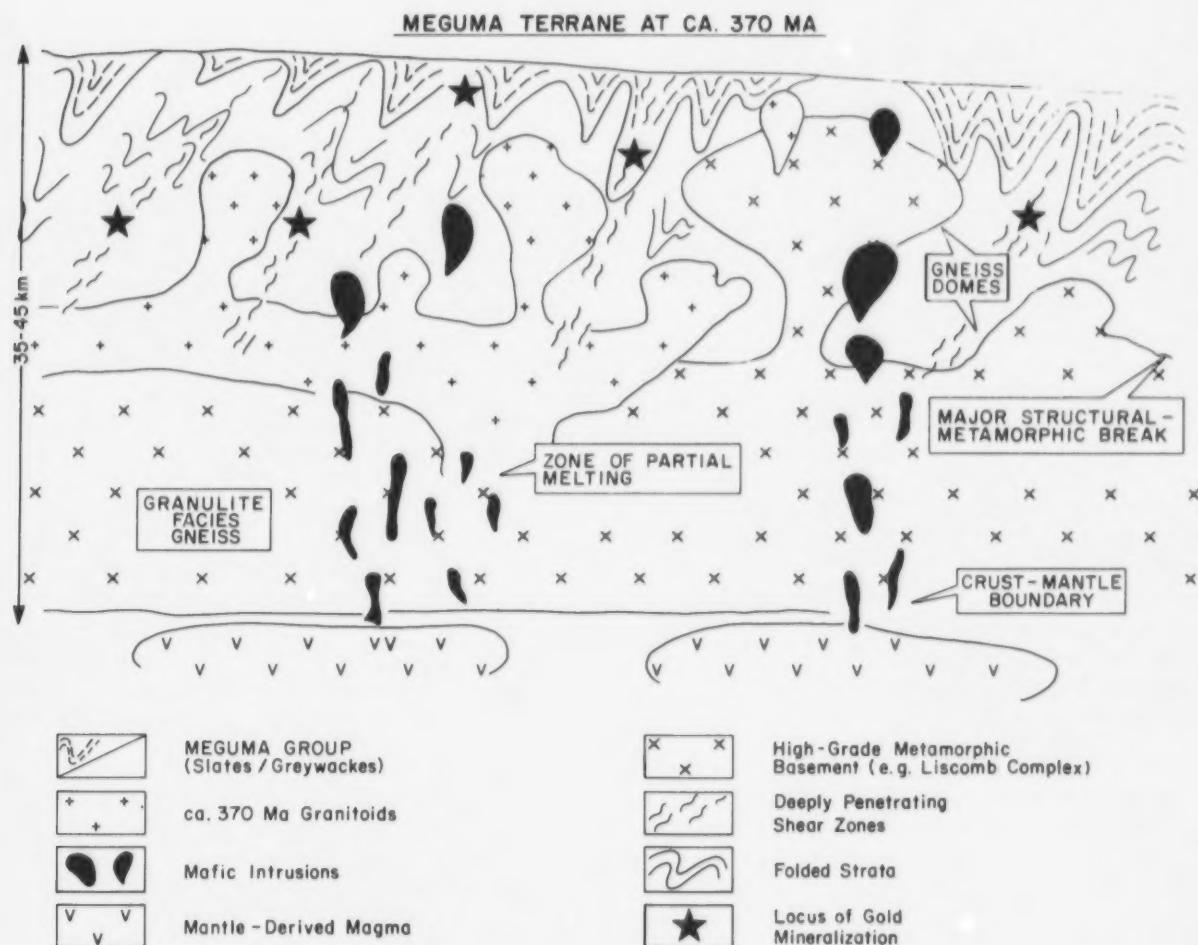


Figure 1. Schematic diagram illustrating the salient aspects involved in the genesis of Meguma-hosted gold deposits.

fluids. With respect to the Meguma deposits, there is little compelling evidence to indicate that a significant component of the ore fluid was of unmodified magmatic origin.

The volume of fluid involved in formation of the gold deposits has not been quantitatively estimated, but field and laboratory evidence previously cited suggests that fluid:rock ratios were high. Similar conclusions have been reached by other workers, for example Kerrich et al. (1977) inferred that large volumes of

fluid must have been focused through auriferous zones in the Yellowknife district on the basis of the oxidation state of iron in vein and wall rocks. The presence of extensive alteration haloes in Meguma Group gold districts is interpreted to reflect the magnitude of the hydrothermal systems that deposited the gold, and the extent of alteration suggests the potential for large deposits is good. Results of ongoing exploration programs bear this point out well and indicate that both vertical and lateral continuity for the mineralized zones are extensive (e.g. 1-2 km and 600-800 m minimum).

The importance of the late deformational event is stressed here because it accounts for deformation of the quartz veins, not the earlier Acadian deformation as is generally thought. Evidence has been presented earlier to demonstrate that regional D₂ fabrics are in fact wrapped about the F₄ folds represented by the deformed quartz veins. Thus, it is inferred that the apparent folding of quartz veins into saddle-reef shapes in districts such as Goldenville (Fig. 1 in Mawer, 1986) and Fifteen Mile Stream (Figs. 2 and 3 in Coates, 1987) resulted from emplacement of veins into active, ductile shear zones. This point alone invalidates many of the previous models on the basis of the time constraints inferred for the age of deformation of the quartz veins.

Of particular relevance to gold is the localization of mineralization in ore shoots. While recognizing the presence of these features, we presently have no satisfactory explanation as to their occurrence and orientation. Future work will address this very important problem.

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PRELIMINARY REPORT ON THE METAMORPHIC HISTORY OF MEGUMA GROUP METASEDIMENTS IN EASTERN NOVA SCOTIA: REGIONAL AND CONTACT METAMORPHISM¹

S. L. Douma

INTRODUCTION

The purpose of this study is to achieve a better understanding of the metamorphic history of Meguma Group metasediments in eastern Nova Scotia. Metamorphic parameters will help define the criteria relevant to gold mineralization. The specific aims of this project are: (1) to establish metamorphic mineral paragenesis relative to regional and contact metamorphism, anomalous thermal effects and structural elements, (2) to document mineral geochemistry of each metamorphic mineral population and (3) subsequently to relate effects of metamorphism to pervasive alteration and mineralization associated with the gold deposits.

Documentation of the metamorphic history of Meguma Group metasediments is currently underway in areas outside of known gold deposits. Petrographic and mineralogical studies of samples collected during the summer of 1987 and by G. K. Muecke in 1982 and 1983 are in progress (Fig. 1). A database of mineral chemistry is being established and will include: (1) analyses of dominant phases within the metamorphic facies (both regional and contact) and within anomalous metamorphic zones, (2) representative analyses from the full range of lithologies observed, (3) mineral profiles across select phases

(i.e. garnet, staurolite) and (4) analyses of mineral phases that define more than one fabric in the rock, in order to determine if the different fabrics can be identified by their mineral chemistry. This fourth aspect is relevant because various workers have recognized at least five phases of deformation in Meguma Group metasediments (O'Brien, 1983; Keppie, 1983; Smith, 1983; Smith et al., 1985).

OBSERVATIONS

The following are descriptions of a typical pelitic rock from each of the following metamorphic zones. These are only preliminary observations based on limited data.

CHLORITE ZONE

Greenschist Facies

Mineralogy: quartz, clastic feldspar, muscovite, chlorite, $\pm$ opaques, tourmaline, rutile, trace abundances of poorly developed biotite

Relative age relationships of diagnostic assemblages: The axial planar shear fabric (S_2 ?) commonly developed in these rocks is defined by muscovite and chlorite. Late stage chlorite porphyroblasts overgrow this shear fabric. Two forms of muscovite can be observed, one developing the

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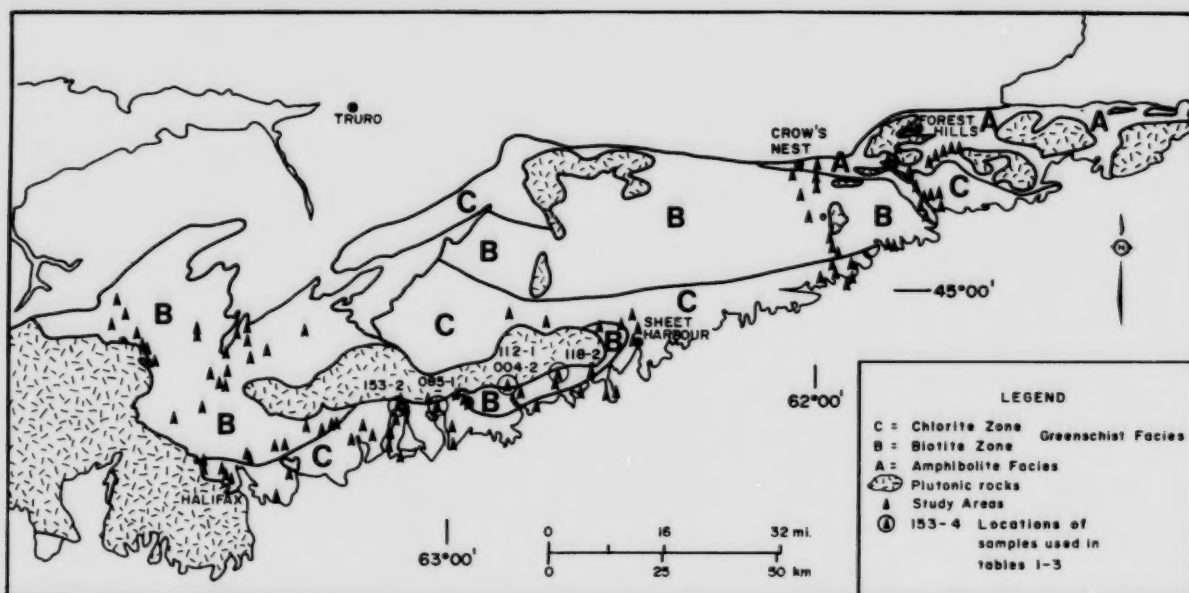


Figure 1. Sample location map of the eastern Meguma Terrane showing metamorphic facies and zones after Keppie and Muecke, 1979.

shear fabric (S_2) and the other larger grains overgrowing this shear fabric.

Absolute age relationships: The greenschist facies metamorphism has been dated at 377 to 400 Ma by $^{40}\text{Ar}/^{39}\text{Ar}$ incremental-release ages derived from whole-rock slate/phyllite samples by Keppie and Dallmeyer (1987). They inferred that these dates approximate the age of growth of white mica aligned parallel to axial planar shear fabrics (labelled S_2 in this text). There is no apparent correlation between metamorphic grade and age.

BIOTITE ZONE

Greenschist Facies

Mineralogy: quartz, clastic feldspar, muscovite, chlorite, biotite, $\pm$ tourmaline, opaques, epidote

Relative age relationships of diagnostic assemblages: The axial planar shear fabric (S_2 ?) typically developed in these rocks is defined by muscovite, chlorite and biotite. At

least two generations of each of these phyllosilicates have developed in some locations either as earlier porphyroblasts that have been deformed by the shear fabric (S_2 ?) or as late phase porphyroblasts overgrowing the shear fabric. In some cases both these generations of porphyroblasts occur in the same sample indicating a continuous growth of the porphyroblasts before, during and after formation of the shear fabric. Biotite grows at the expense of chlorite and muscovite. Late stage crenulation cleavage (S_3 ?) deforms the muscovite - chlorite - biotite shear fabric in the eastern sector of this study area.

Amphibolite Facies Crow's Nest area, Guysborough County

Mineralogy: quartz, feldspar, biotite, muscovite, opaques $\pm$ staurolite, cordierite, garnet, tourmaline, trace chlorite

A strongly developed, continuous, penetrative axial planar shear fabric (S_2 ?) is common. This shear fabric is

typically defined by biotite and muscovite. Poikiloblastic, quartz-rich staurolite and cordierite post-date this shear fabric. Garnet inclusions in staurolite are common.

A well developed, tight crenulation cleavage (Fig. 2) ($S_3?$) post-dates the muscovite and biotite ($S_2?$) shear fabric and deforms staurolite and cordierite porphyroblasts. Garnet and large idioblastic biotite, muscovite and minor chlorite overgrow this crenulation cleavage.

CONTACT AUREOLE

Musquodoboit and South Mountain Batholiths

Mineralogy: quartz, clastic feldspar, muscovite, biotite, $\pm$ cordierite, andalusite, tourmaline, opaques, pinite (altering cordierite)

Relative age relationships of diagnostic assemblages: Cordierite and andalusite porphyroblasts post-date the

S_2 shear fabric (Fig. 3) (where preserved) in the South Mountain Batholith aureole. Cordierite porphyroblasts associated with the Musquodoboit Batholith aureole commonly post-date the S_2 axial planar shear fabric but also pre-date the axial planar shear fabric ($S_2?$ or $S_4?$) (Fig. 4). If this shear fabric represents the same deformational event (i.e. S_2), then cordierite growth was continuous with the development of shear fabric. It may also indicate that the S_2 shear fabric was remobilized during the development of S_4 , which subsequently deformed the cordierite porphyroblasts. Cordierite pre-dates the S_3 crenulation cleavage developed in the eastern sector of the Musquodoboit Batholith contact aureole (Fig. 3).

Mineral Chemistry: The mineral chemistry of select chlorite, muscovite and trace biotite grains for pelite and metagreywacke associated with the Musquodoboit Batholith contact aureole is displayed in Tables 1, 2 and 3.

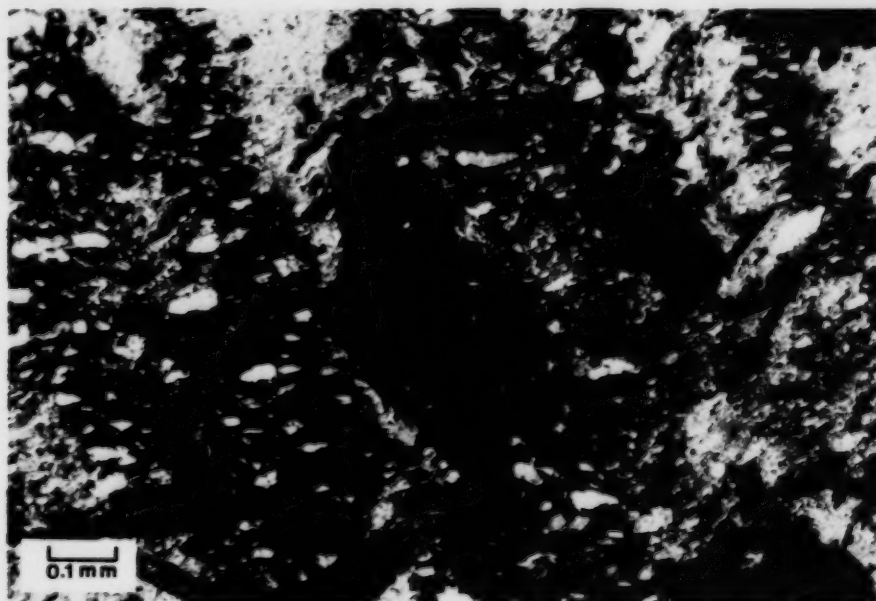


Figure 2. Sample 82-160. Staurolite-garnet-biotite-muscovite schist (amphibolite facies). The well developed crenulation ($S_3?$) overprints the muscovite shear fabric (S_2). The biotite porphyroblast post-dates the S_3 crenulation cleavage.

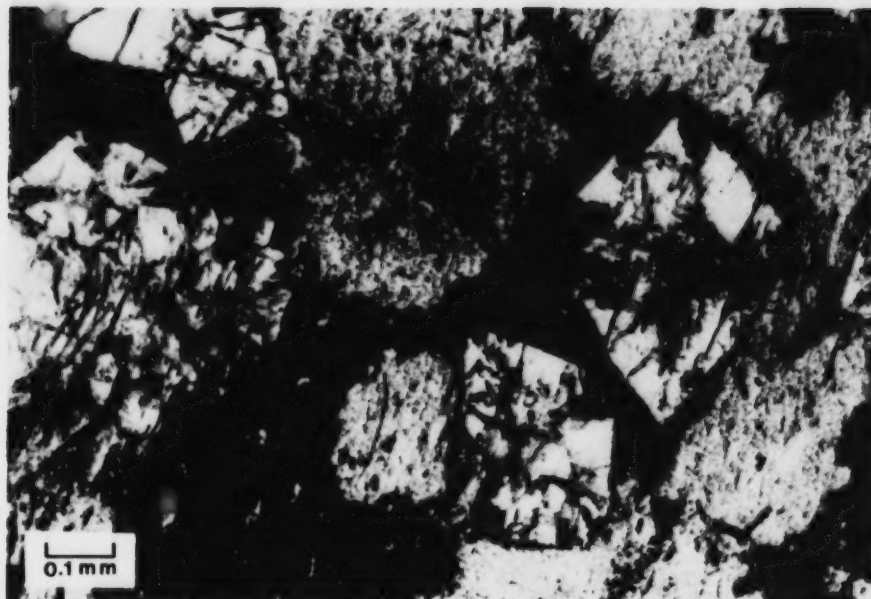


Figure 3. Sample 042-1. Cordierite-andalusite-biotite hornfels from the contact aureole of the SMB overprinting the chlorite zone. Porphyroblasts of cordierite and andalusite overgrow a fine grained, altered matrix.

RETROGRADE METAMORPHIC EFFECTS

Preliminary results show the following:

(1) Fine grained sericite alteration of clastic feldspar is common in the chlorite grade.

(2) Biotite is often altered to chlorite, which post-dates the S_2 shear fabric in the biotite grade.

(3) Staurolite is partially altered by sericite and biotite is moderately chloritized in the amphibolite facies. Garnet is locally chloritized and clastic feldspar is moderately sericitized.

(4) Cordierite is commonly retrograded to pinite in the contact aureole. This post-dated or was synchronous with thermal alteration. Biotite is commonly chloritized and matrix minerals associated with the South Mountain Batholith aureole (predominantly quartz and feldspar) have been altered by kaolinization and sericitization.

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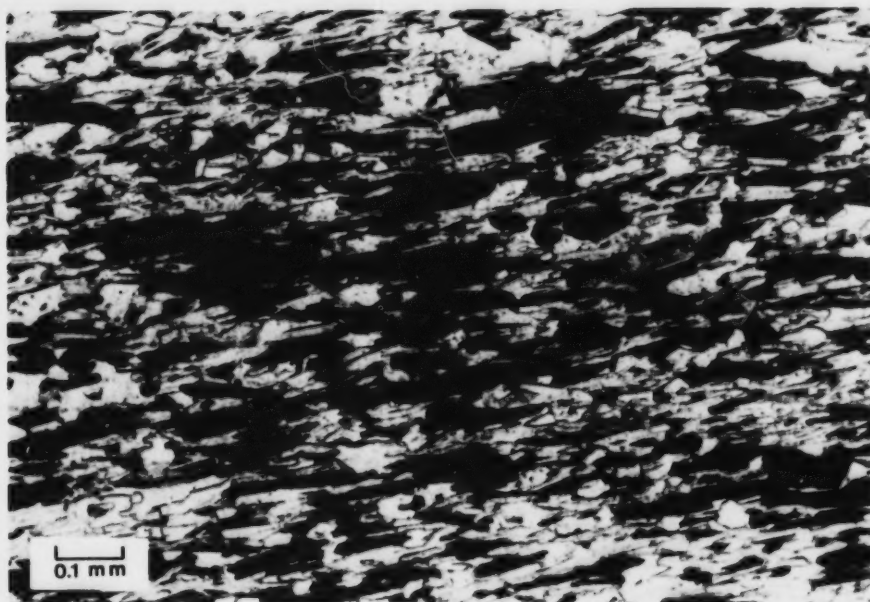


Figure 4. Sample 112-2. Cordierite-biotite-muscovite schist from the contact aureole associated with the Musquodoboit Batholith overprinting the biotite zone. Note the moderately developed shear fabric defined by biotite and muscovite. Analysis in Table 3.

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Table 1. Chlorite analyses from the Musquodoboit Batholith contact aureole.

SAMPLE	118-2	118-2	118-2	153-2	153-2
ANALYSES	6	7	8	1	3
ROCK TYPE	pelite	pelite	pelite	metagreywacke	metagreywacke
METAMORPHIC GRADE	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	chlorite zone/ contact	chlorite zone/ contact
LOCATION	core	core	core	core	core
SiO ₂	23.71	24.01	23.91	24.14	23.22
TiO ₂	0.13	0.13	0.12	0.10	0.11
Al ₂ O ₃	22.93	21.53	21.75	22.94	23.90
Cr ₂ O ₃	0.02	0.05	0.05	0.01	0.03
FeO	23.74	23.37	22.98	24.37	24.55
MnO	0.44	0.35	0.36	0.32	0.34
MgO	15.77	15.82	15.84	13.85	12.88
CaO	0.02	0.02	0.02	0.05	0.04
Na ₂ O	0.00	0.00	0.00	0.00	0.01
K ₂ O	0.00	0.00	0.00	0.00	0.00
P ₂ O ₅	0.00	0.00	0.00	0.00	0.00
H ₂ O	11.29	11.11	11.10	11.16	11.04
Total	98.05	96.39	96.13	96.94	96.12

Legend for samples analyzed in Tables 1 through 3.

118-2 - Cordierite-muscovite-biotite pelite. Chlorite alters the biotite. Sample from the biotite zone within the Musquodoboit Batholith contact aureole.

153-2 - Fine grained muscovite-chlorite metagreywacke. Muscovite and chlorite define a weak anastomosing shear fabric. Sample from the chlorite zone.

004-2 - Cordierite-biotite-muscovite schist from the biotite zone within the Musquodoboit Batholith contact aureole.

112-1 - Cordierite-biotite-muscovite schist from the biotite zone within the Musquodoboit Batholith contact aureole.

085-1 - Cordierite-muscovite-biotite schist. A strong muscovite shear fabric is developed. Coarse grained biotite overgrows the muscovite shear fabric. The sample is from the chlorite zone within the Musquodoboit Batholith contact aureole.

Table 2. Biotite analyses of samples from the Musquodoboit Batholith contact aureole.

SAMPLE	085-2	085-2	085-2	112-1	112-1	112-1	112-1	112-1	112-1	112-1	112-1	004-2	004-2	004-2	118-2	118-2	118-2
ANALYSES	2-1	2-2	2-3	2	3	4	5	6	1	1	1	2	3	3	10	11	9
ROCK TYPE	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite
METAMORPHIC GRADE	chlorite zone/ contact	chlorite zone/ contact	chlorite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact
LOCATION	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core
SiO ₂	34.81	35.00	34.65	34.13	33.57	34.00	34.58	33.50	34.70	34.40	34.09	34.28	34.09	34.28	33.36	35.63	34.73
TiO ₂	1.57	1.46	1.64	3.08	3.02	2.89	2.75	2.76	2.62	2.73	2.87	2.79	2.87	2.79	1.32	1.57	1.43
Al ₂ O ₃	19.08	19.32	19.23	19.58	19.30	20.07	19.95	19.29	20.23	18.85	18.52	19.69	18.52	19.69	19.70	18.83	19.13
Cr ₂ O ₃	0.08	0.07	0.08	0.07	0.10	0.06	0.10	0.05	0.11	0.06	0.00	0.05	0.00	0.05	0.05	0.05	0.06
FeO	20.14	20.56	20.19	21.36	20.92	20.44	20.86	20.72	20.38	21.08	21.39	21.14	21.39	21.14	20.34	19.14	19.62
MnO	0.25	0.23	0.27	0.34	0.27	0.30	0.28	0.25	0.28	0.11	0.14	0.09	0.14	0.09	0.22	0.23	0.19
MgO	9.76	10.10	9.65	7.67	7.70	7.92	7.97	7.31	7.47	7.31	7.46	7.55	7.46	7.55	10.93	10.51	10.27
CaO	0.03	0.02	0.03	0.03	0.00	0.04	0.03	0.04	0.06	0.04	0.08	0.07	0.08	0.07	0.03	0.02	0.04
Na ₂ O	0.18	0.19	0.19	0.12	0.11	0.15	0.14	0.15	0.16	0.08	0.12	0.12	0.16	0.12	0.18	0.20	0.22
K ₂ O	9.10	8.89	9.32	9.65	9.52	9.79	9.83	9.36	9.18	8.82	8.67	9.19	8.67	9.19	6.83	8.19	7.67
P ₂ O ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H ₂ O	3.91	3.94	3.91	3.91	3.85	3.91	3.94	3.81	3.92	3.83	3.82	3.89	3.82	3.89	3.86	3.93	3.88
Total	98.91	99.78	99.16	99.94	98.36	99.57	100.43	99.24	99.11	97.31	97.16	98.86	97.16	98.86	96.82	98.30	97.24

Table 3. Muscovite analyses from samples from the Musquodoboit Batholith contact aureole.

SAMPLE	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2	085-2
ANALYSES	1-2	1-3	6-1	6-2	6-3	1	2	3	4	5	6	1-1	1-2	1	2	2	3
ROCK TYPE	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite	pelite
METAMORPHIC GRADE	chlorite zone/ contact	chlorite zone/ contact	chlorite zone/ contact	chlorite zone/ contact	chlorite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact	biotite zone/ contact
LOCATION	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core	core
SiO ₂	48.98	49.32	48.42	45.68	45.24	44.14	47.22	44.08	46.51	45.47	46.54	51.20	48.17	51.22	47.71	49.93	49.93
TiO ₂	0.18	0.36	0.40	0.36	0.43	0.97	0.99	0.91	0.47	0.86	0.89	0.15	0.38	0.16	0.11	0.10	0.09
Al ₂ O ₃	33.16	32.38	31.86	35.18	34.97	35.44	36.58	35.32	36.34	36.07	36.05	31.30	29.41	29.78	37.43	35.69	36.54
Cr ₂ O ₃	0.01	0.03	0.00	0.01	0.02	0.01	1.06	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
FeO	2.81	2.45	4.47	2.73	2.71	0.92	1.06	0.90	0.92	0.97	0.92	3.20	4.45	2.19	0.41	0.45	0.46
MnO	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	1.10	1.26	1.81	0.65	0.49	0.42	0.52	0.51	0.57	0.52	0.51	1.70	2.07	1.29	0.21	0.25	0.36
CaO	0.00	0.06	0.00	0.06	0.03	0.05	0.02	0.03	0.04	0.02	0.01	0.00	0.00	0.68	0.03	0.05	0.00
Na ₂ O	0.58	0.58	0.54	0.62	0.70	0.43	0.41	0.36	0.50	0.46	0.40	0.52	0.45	1.74	1.74	1.41	1.41
K ₂ O	9.26	9.13	9.18	9.38	9.80	9.47	9.92	9.67	9.37	10.13	10.11	8.68	8.38	7.49	7.13	6.85	7.33
P ₂ O ₅	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H ₂ O	4.56	4.55	4.54	4.47	4.44	4.37	4.60	4.36	4.53	4.48	4.54	4.61	4.40	4.55	4.56	4.50	4.67
Total	100.64	100.18	101.25	99.15	98.83	96.22	101.34	96.16	99.45	98.98	99.99	101.36	97.72	99.08	100.70	97.14	100.79



EXPLORATION POTENTIAL FOR ARGENTIFEROUS BASE METALS AT THE WALTON DEPOSIT, HANTS COUNTY, NOVA SCOTIA¹

J. M. Patterson

INTRODUCTION

The Mississippian, sediment-hosted Walton deposit was first noted in 1894 as a small barite outcrop. Renewed interest in 1940 led to the commencement of mining operations in 1941 as an open pit barite mine. Mining progressively expanded and on cessation of mining in early 1978 approximately 5.0 million tons² of >90% BaSO₄ had been mined (Patterson, 1986). In the late 1950s base metals with associated high silver values were discovered and from 1961 to 1970 approximately 400,000 tons were milled with a head grade of 0.56% Cu, 4.33% Pb, 1.44% Zn and 10.9 oz. Ag/ton. At current (February 1988) metal prices this translates to a per ton value of \$140 US, with silver contributing approximately 58% of the value, while the present value of total metal recovered in concentrate is approximately \$53 million US. Though exploration and development headings are present down to the 1650 ft. level, production was confined to levels above the 1030 ft. level. The property is currently being explored by the license holder.

STRATIGRAPHY

The Walton Mine is located about 18 miles northeast of Windsor and a few miles inland from the Minas Basin of the Bay of Fundy (Fig. 1). The Walton area is underlain predominantly by

sedimentary rocks of Mississippian age (Fig. 1). The major bedrock contact of economic importance is that between the Horton Group, comprising red and grey sandstone, shale, siltstone, arkose and conglomerate, and the Windsor Group limestone, minor sandstone, evaporites and red shale.

The Macumber and Pembroke Formations are hosts to the mineralization. The Macumber Formation is regarded as the base of the Windsor Group as it represents the influx of shallow marine conditions following the continental conditions represented by the underlying Horton Group sediments. The Macumber Formation ranges from <1 to >20 ft. in thickness and overlies the Cheverie Formation of the Horton Group. Lithologically, the Macumber Formation consists of light brownish-grey, essentially unfossiliferous, finely bedded limestone that parts readily along bedding planes. Locally, finely bedded calcareous sandstone and siltstone occur near the base of the formation. Boyle (1972) states that some evidence of algal origin for the limestone is present and that in some cases the limestone is petroliferous. Indeed a diamond-drill hole on the 1650 ft. level was stopped due to water, oil and gas.

The Pembroke Formation (Boyle, 1972) varies from 10 to 100 ft., is laterally discontinuous and conformably

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

² All units cited in this paper are Imperial, in order to conform to mine records.

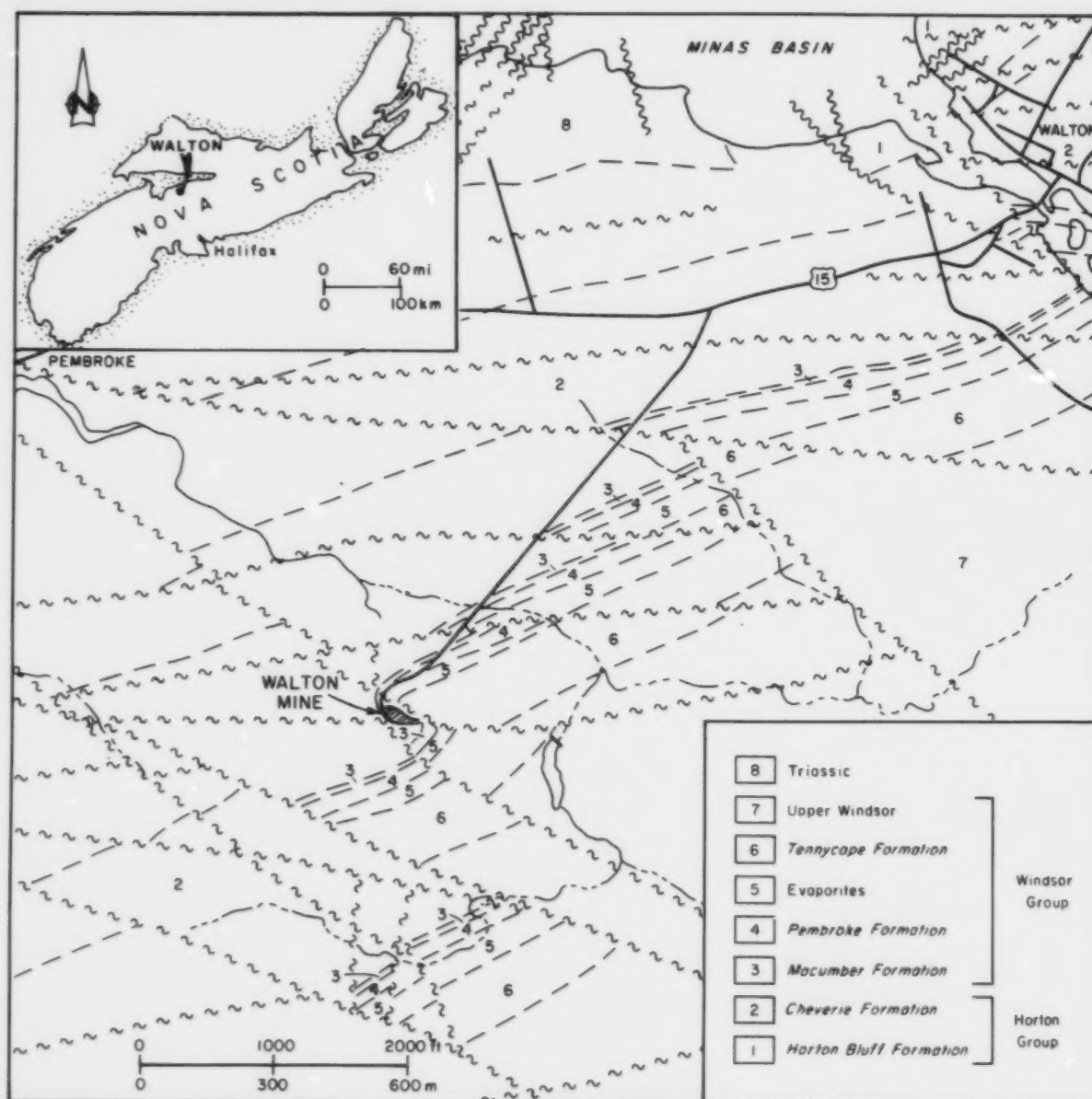


Figure 1. Location of the Walton Mine and local geology (after Boyle, 1972).

overlies the Macumber Formation. The rocks are reddish limestone conglomerate or breccia, containing pebbles and fragments of Macumber Formation limestone in a reddish calcareous matrix (Boyle, 1972). Algal characteristics are locally observed and the limestone conglomerate is essentially unfossiliferous. Nearly

all the Pembroke Formation rocks are petroliferous.

Overlying the Pembroke Formation in the lower parts of the mine is an evaporitic series predominantly consisting of anhydrite. Red sandstone and shale of the Tennycape Formation overlie these evaporites in the lower

mine levels but are in direct contact with the Pembroke Formation in the upper levels of the mine (Fig. 2).

STRUCTURE

Carboniferous rocks in the Walton area lie unconformably on the Cambro-Ordovician Meguma Group basement and are openly folded into a series of northeast-trending folds (Fig. 1). Two major sets and one minor set of faults cut the Carboniferous rocks: a general east-striking set, a northwest-striking set and a minor northeast-striking set. Vertical displacements of 1000 ft. may occur on these east-west faults with throws to north or south. Nearly all east-west faults have related mineralization and the Walton orebody is associated with such a fault.

CURRENT RESEARCH

Drill logs, plans and sections, and relevant assay data were recovered from the mine vault at Walton. New sections and plans were drawn to display both the geometry of the deposit and the relationship between geology and ore distribution. Most of the mining activity focused on the area of the D Baseline and barite was the commodity of primary economic interest to the exploiting company. Since the majority of the massive barite has been mined out, the present study is aimed at determining the continuity of sulphide mineralization both along strike and to depth in an attempt to define drill targets which may indicate sufficient reserves to warrant renewed exploitation.

Figure 2 is a composite cross-section of the deposit in the area that was mined and shows the relationship of the barite deposit to the argentiferous sulphide zone. The sulphide zone was discovered approximately 15 years after commencement of barite production and tops out around 270 ft. below surface.

Mining production took place from surface to the 1030 ft. level and exploration was carried out down to the 1650 ft. level. The cross-section shows the massive barite deposit with the argentiferous sulphide zone in the footwall from approximately 270 ft. to around 1100 ft. At this level the massive barite deposit gives way to a barite-sulphide zone close to the contact between the Pembroke Formation and the overlying evaporitic horizon. It is also noticeable that the hanging wall is anhydrite below 1100 ft. whereas above this level, where the massive barite deposit is developed, the hanging wall comprises shale and sandstone of the Tennycape Formation.

Figure 3 is a composite plan view showing the relationship between the barite and sulphide deposits. In the D Baseline area the sulphides are tucked into the footwall of the barite deposit, plunge eastward and are associated with a strong northwest-trending fault zone.

Study of the sulphide potential along the South Limb or B Baseline reveals that, compared with the D Baseline, a greater strike extent of mineralization is exposed over the 3 levels on which development has taken place. Barite mineralization is much more intimately associated with the sulphides and several sulphide lenses have been identified along the B Baseline. Drilling shows these lenses to continue above and below the levels and very limited stoping has taken place. Stratum contours on the Horton/Windsor contact (Fig. 4) indicate no significant crosscutting features in the geology, however any structure here may parallel the plane of the section.

Plotting of metal content values for Cu, Pb, Zn, Ag and BaSO_4 indicate several distinct 'shoots' or 'lodes' within the overall mineralized body. These plunge (Fig. 4) at an oblique angle to the Horton/Windsor contact in

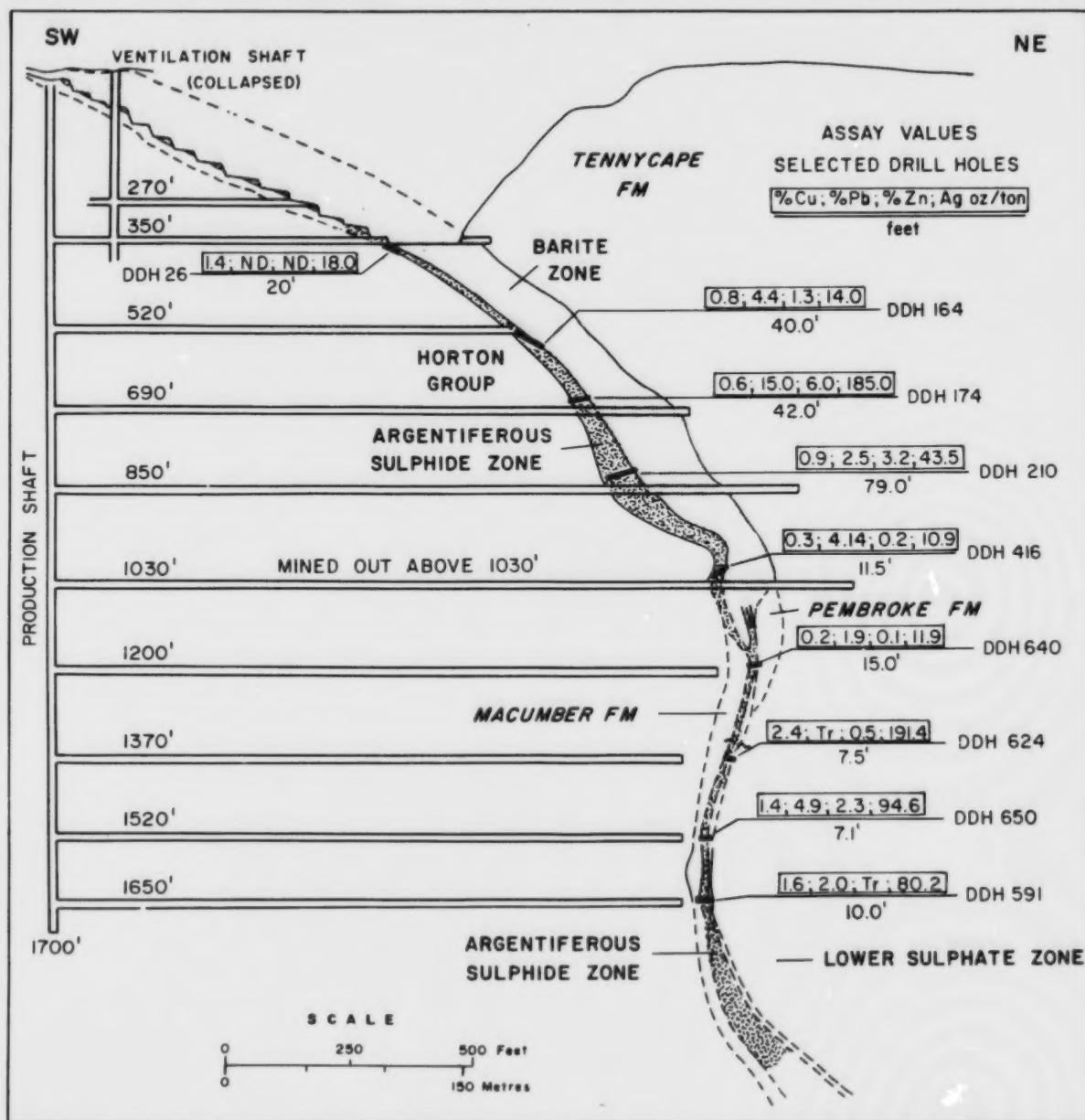


Figure 2. Composite cross-section of the Walton Mine.

a southwest direction at approximately 40° from the horizontal in the plane of the section. Drill targets are present both up and down plunge of these shoots. Ore grade mineralization is present on the 1030 ft. level and the presence of ore grade mineralization on

the 1650 ft. level in the D Baseline area suggests that first stage potential exists to at least this level in the B Baseline area. The overall depth potential is governed by the geometry of the pre-Carboniferous basement and associated faults in the

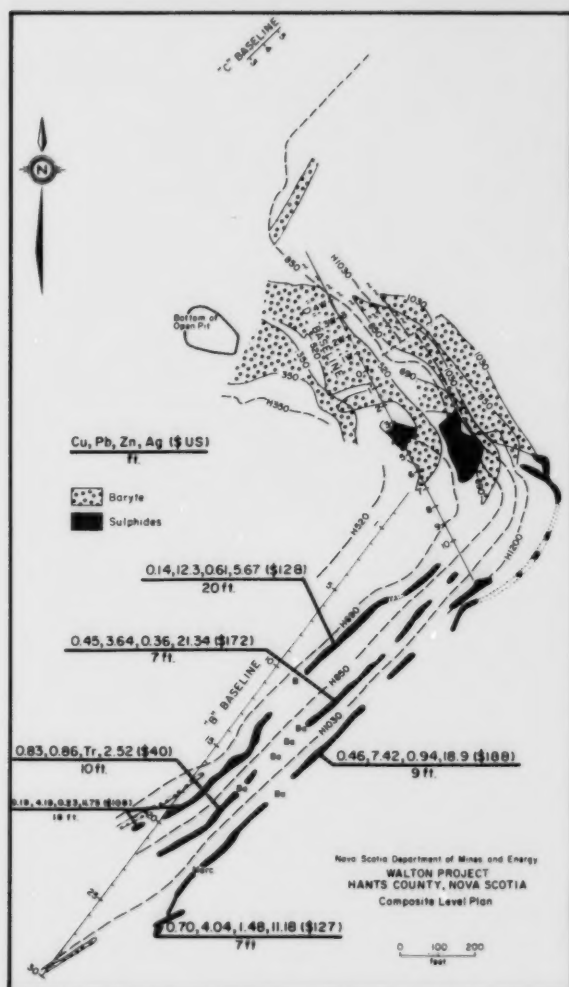


Figure 3. Composite level plan showing ore relationships and values (\$US) at the Walton Mine.

immediate area of the mine.

MINERALIZATION AND MINERALOGY

The massive barite is compact and fine grained in texture. Boyle (1972) describes it as cherty in appearance and interprets this barite as a product of replacement of the Macumber and Pembroke Formation limestones. Sulphides occur both in massive form and as breccia and fracture fill. Siderite is closely associated with the mineralization and the paragenetic sequence, as determined by Boyle

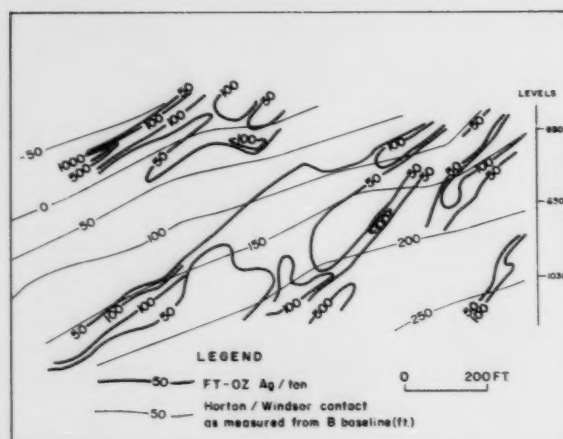


Figure 4. Longitudinal section of the Walton deposit, B Baseline, showing relationship between ore shoots and the Horton/Windsor Contact.

(1972), indicates that silver mineralization occurred late in the sequence. No clear relationship between silver distribution and other metals has as yet emerged, but polished section and electron probe studies confirm the presence of discrete silver minerals.

POTENTIAL

The immediate potential for meaningful addition to argentiferous base metals at Walton is up and down plunge from the shoots as outlined (Fig. 4). The recognition of cohesive shoots of sulphide mineralization will allow for better control on exploration drilling but will also cause the tonnage potential to be reduced. Up plunge potential exists in the B Baseline area but, by analogy with the D Baseline, these upper levels may contain barite only where the sulphides have died out updip. Down plunge potential will be controlled by the amplitude of folding and the depth of favourable host rocks. However, by analogy with the D Baseline, first order potential persists to the 1650

foot level as ore grade sulphides are present at this depth on the D Baseline.

Assuming the continuation of the ore shoots down to 1700 ft. below surface and the maintenance of the same thickness and width, the two most southwesterly ore shoots could contain some 250,000 tons below the 1030 ft. level. The ore content of this 250,000 tons is difficult to estimate but grades similar to those outlined in the pods (Fig. 3) could be expected. The up plunge potential is more difficult to assess as the lithology may change from sulphides to barite.

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YAVA BASE METAL DEPOSIT: NEW MINERAL POTENTIAL RESULTING FROM THE 1987 DIAMOND-DRILLING PROGRAM¹

J. M. Patterson

INTRODUCTION

The Yava base metal deposit is situated in the Salmon River basin some 25 miles southwest of Sydney, Cape Breton County (Fig. 1). A shallow

diamond-drilling program undertaken in 1986 identified an area of relative zinc enrichment to the west of the area that had been mined between 1979 and 1981 (Patterson, 1987). These interesting results were followed up by a drill program comprising 1119 ft.² in

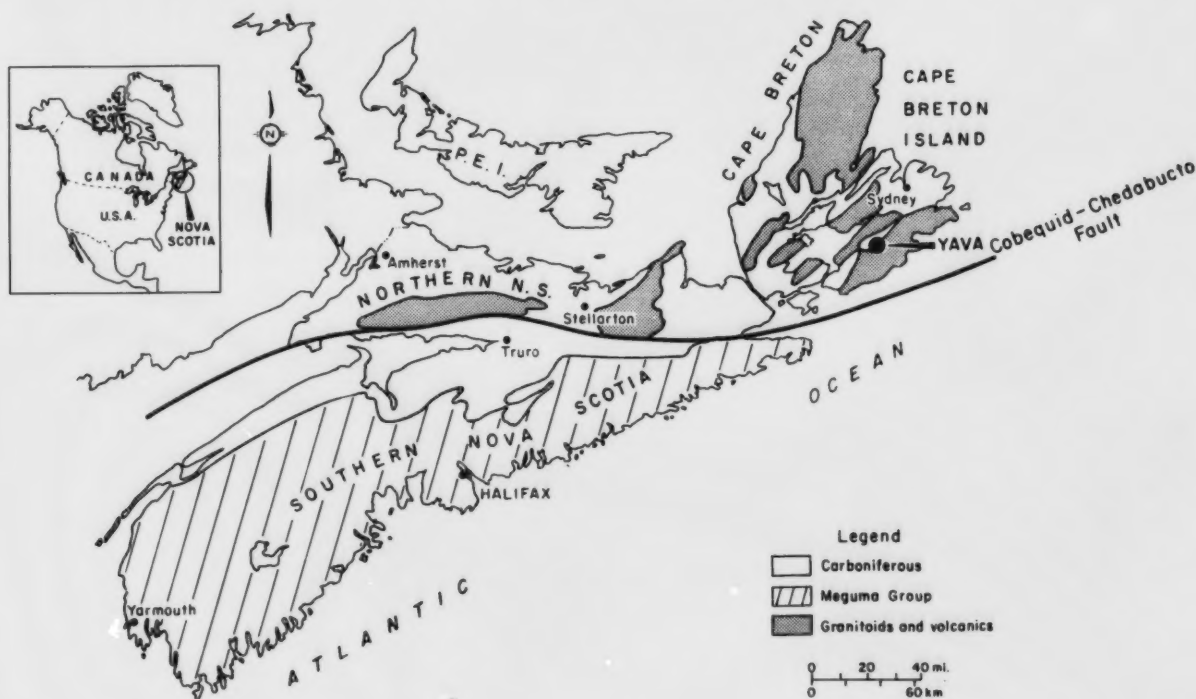


Figure 1. Simplified geological map of Nova Scotia showing the location of the Yava deposit.

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

² All units cited in this paper are Imperial, to conform to mine and diamond-drilling records

9 vertical drillholes. The drilling was undertaken by the Drilling Division of Nova Scotia Department of Mines and Energy during the period 18 March to 6 May 1987.

OBJECTIVES OF THE DRILL PROGRAM

Since assuming ownership of the Yava deposit in 1983, following the bankruptcy of the operator in 1981, the Province has been assessing the potential of the deposit as a low grade, open pit lead mine. During this study the previously perceived analogy with the Laisvall deposit in Sweden (Rickard et al., 1979) was further developed and the 1986 drilling program provided greater support for this analogy by identifying a coherent area where a relative enrichment in zinc values occurred (Fig. 2). Objectives of the 1987 program were to investigate the extent of this zinc-rich area and attempt to locate higher grade values.

GEOLOGY

The Yava lead deposit, hosted by Pennsylvanian sandstone of the Riversdale Group (Boehner and Prime, 1985), occurs on the southeast flank of the Salmon River Sub-basin, an outlier comprising predominantly Upper Carboniferous, continental clastic deposits of the Canso Group. The syncline plunges gently to the southwest, is faulted on the northwest margin and sedimentary rocks on the southeast flank, where the deposit is situated, dip gently northwest at 15° (Patterson, 1988). The Precambrian and Cambrian sequences on either side of the outlier are intruded by granitoid plutons of pre-Carboniferous age.

The local basement is represented by a brick red quartz porphyry (rhyolite in the mine terminology) which is considered to be a high level intrusive within the granitoid pluton. The overlying Lower Carboniferous rocks are represented by the Windsor Group,

comprising conglomerate, talus breccia, limestone with varying evaporitic content, and black, green and maroon siltstone and shale. The top of the Windsor Group is marked by a nodular calcareous horizon interpreted to be a calcrete and representing a disconformity prior to the onset of continental clastic sedimentation. The Windsor Group varies in thickness from <1 to approximately 550 ft. in the Yava area.

The major part of the Salmon River Sub-basin consists of clastics of Late Carboniferous age. The basal unit is predominantly a medium grained, grey-green arenaceous sandstone with interbedded conglomerate and mudstone. Coalified plant material is common and the unit is up to 800 ft. thick.

The paleogeographic history inferred from the above stratigraphy reflects 4 main episodes. (1) The pre-Carboniferous quartz porphyry basement was partially subdued and filled in by scree accumulation resulting from subaerial weathering. (2) The Carboniferous commenced with a marine transgression represented by the Windsor Group shale, siltstone, limestone and evaporites. (3) A period of emergence followed, marked by the calcrete horizon at the top of the Windsor Group. This was subsequently followed by (4) deposition of continental clastics of the Riversdale Group in a fluvial environment during the Late Carboniferous. Initially these deposits were confined to depressions but deposition progressively overstepped the basement highs.

DRILLING PROGRAM

During the spring of 1987 the Nova Scotia Department of Mines and Energy drilling section completed 9 vertical surface drillholes totalling 1119 ft. in the Yava West Zone (Fig. 2 and Table 1). Table 2 displays the intersections in feet of major units cut in the

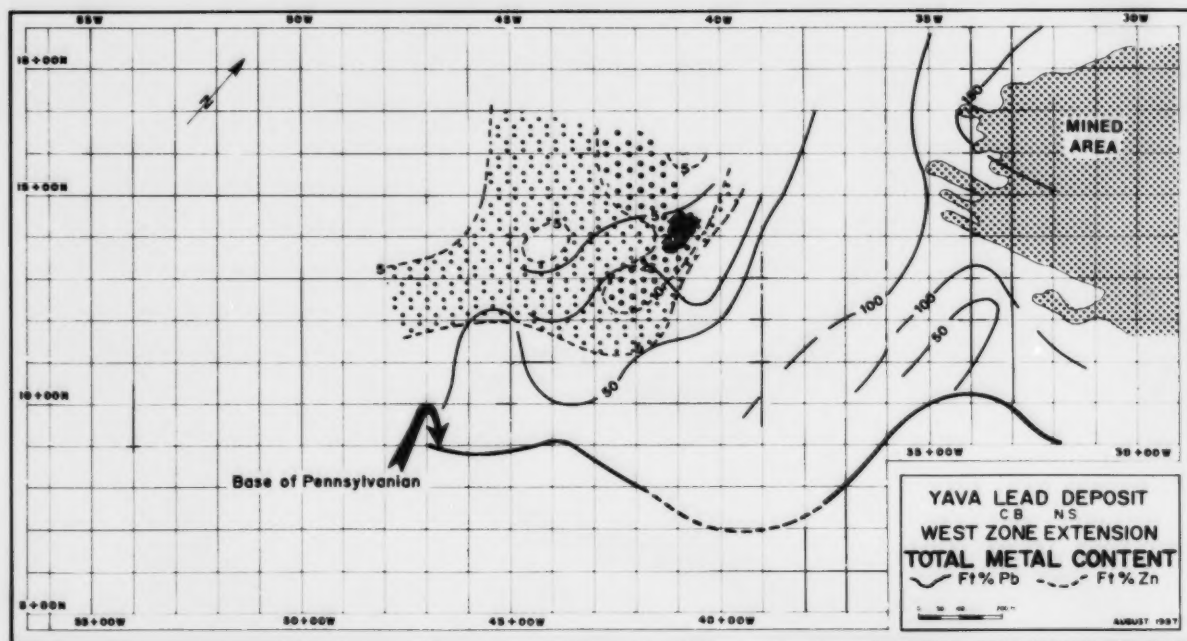


Figure 2. Yava West Zone extension. Total metal content shows the northward increase in Zn values with decreasing Pb values.

Table 1. Details of the 1987 diamond-drill program.

DDH#	DIP	WEST	NORTH	ELEVATION (ft.)	TOTAL DEPTH (ft.)
413	-90	42+10	16+03	4948.69	97
414	-90	43+18	16+00	4949.24	106
415	-90	44+25	16+16	4950.69	78
416	-90	45+17	16+06	4949.98	77
417	-90	43+07	14+91	4948.51	121
418	-90	41+94	15+09	4952.69	172
419	-90	40+87	16+02	4948.23	139
420	-90	40+85	13+97	4954.87	187
421	-90	42+10	12+51	4958.91	142

drillholes and the weighted averages for Pb, Zn and Ag over the sampled lengths.

One of the major controls on mineralization at Yava is basement topography, with lead mineralization

occurring in sandstone within depressions between basement topographic highs (Fig. 3). This model has been used successfully as an exploration guide and the recognition of such a depression west of the mined area was a factor in locating both the

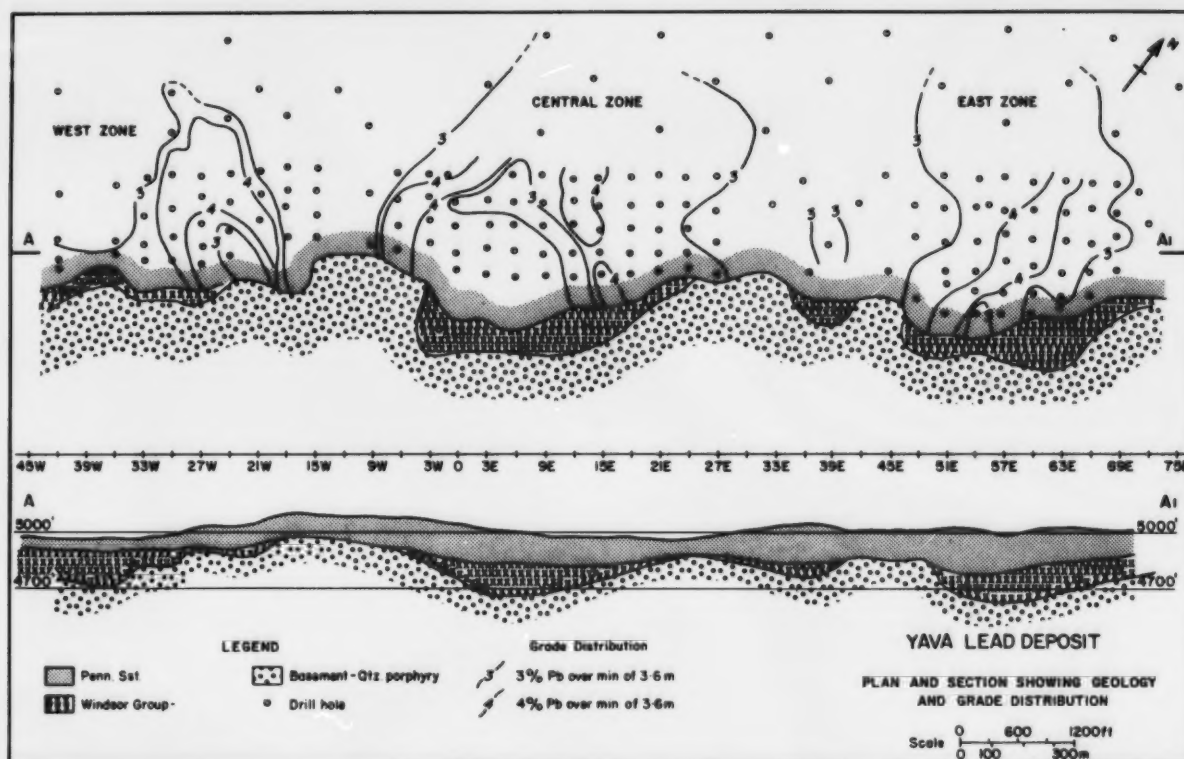


Figure 3. Plan and section of the Yava deposit showing geology and paleotopographic controls on ore grade.

1986 and the recently completed 1987 drill programs.

Table 2 displays the assay results from the 1987 program, while Figure 2 demonstrates that the area of zinc enrichment has been confirmed and extended. The dominant zinc mineralization occurs as disseminated, very pale, interstitial sphalerite, whereas the highest individual zinc assays are associated with more massive pyrite and coal fragments. The pale, disseminated sphalerite occurs with fine disseminated pyrite and sections approaching 1% Zn occur in clean sandstone. The 1987 drilling program has confirmed the presence of a basement high to the west of the known mineralized zone, thus defining the

western limits of the immediate target area, and has also confirmed that significant zinc grades are open to the north.

POTENTIAL AT YAVA

Both the 1986 (Patterson, 1987) and the 1987 drilling programs have firmly established the zinc potential at Yava. Zinc grades approaching 1% are present over mineable widths and values in excess of 2% Zn occur associated with heavy pyrite and coal debris over short lengths (Fig. 2 and Table 2).

Previous studies (Bonham, 1983) have stated that lead mineralization at Yava is closed off downdip. The

Table 2. Assay results from the 1987 drill program.

DDH	PENNSYLVANIAN SANDSTONE	WINDSOR GROUP	RHYOLITE BRECCIA	RHYOLITE	TOTAL DEPTH	-----ASSAYS-----					
						FROM	TO	LENGTH	Pb%	Zn%	Ag ppm
413	92.00	97.00	-	-	97.00	59.10	87.10	28.00	<0.01	0.59	1
424	75.40	97.00	106.00	-	106.00	48.60	55.00	6.40	<0.01	0.47	<1
						68.50	75.40	6.90	0.03	0.75	<1
415	64.30	72.40	0	78.00	78.00	40.70	50.40	9.70	<0.01	0.58	<1
						60.00	63.00	3.00	<0.01	0.27	-
416	70.20	71.30	0	77.00	77.00	45.30	62.00	16.70	0.01	0.38	<1
417	66.60	108.70	119.30	121.00	121.00	29.00	37.10	8.10	<0.01	0.45	<1
						45.60	50.80	5.20	<0.01	0.54	<1
418	88.10	167.30	168.30	172.00	172.00	58.70	79.50	20.80	0.21	0.62	1
419	94.90	126.90	139.00	-	139.00	51.60	64.00	12.40	<0.01	0.43	<1
420	85.60	168.00	187.00	-	187.00	43.00	52.50	9.50	0.17	1.02	<1
						66.50	83.50	17.00	0.94	0.64	
421	55.10	132.20	137.50	142.00	142.00	27.70	43.50	15.80	0.74	0.73	1
						43.50	54.80	11.30	2.90	0.05	2.0

failure of a deeper drill program undertaken by the operators in 1981 to extend ore grade mineralization downdip over a broad front gave rise to this belief. Figure 4 shows the relationship of lead grade in the first cycle sandstone to the restored palaeorelief on the Windsor-Riversdale disconformity. The sharp north-trending cutoff along the 3% Pb contour coincides with the development of a positive ridge running in the same direction. The plans and simplified sections presented in Figure 4 show the higher grade areas to be associated with palaeodepressions. This reflects the well documented palaeotopographic control of grade in the orebody as a whole. The palaeoridge rises steadily to the northwest and there is a suggestion that the relief may again descend into another depression on the northwesternmost part. This narrow col corresponds to the area where the 3% Pb contour has cut through the ridge and appears to be expanding again to the northwest. This ridge parallels the southeast margin of the basin and is perpendicular to the generally accepted, and better documented, palaeorelief direction. If a parallel depression exists then possibilities for renewed development of ore grade material in this depression are enhanced.

FUTURE EXPLORATION

The present state of knowledge suggests two main fields of further exploration at Yava. The often postulated zinc potential has been supported by outlining a distinct area with significant zinc values over mineable widths. Further follow up of this potential must be undertaken as future viability at Yava may very well depend on developing reserves of a second metal other than lead. The second field requiring additional exploration is an investigation of the possible parallel depression downdip which could contain significant mineralization.

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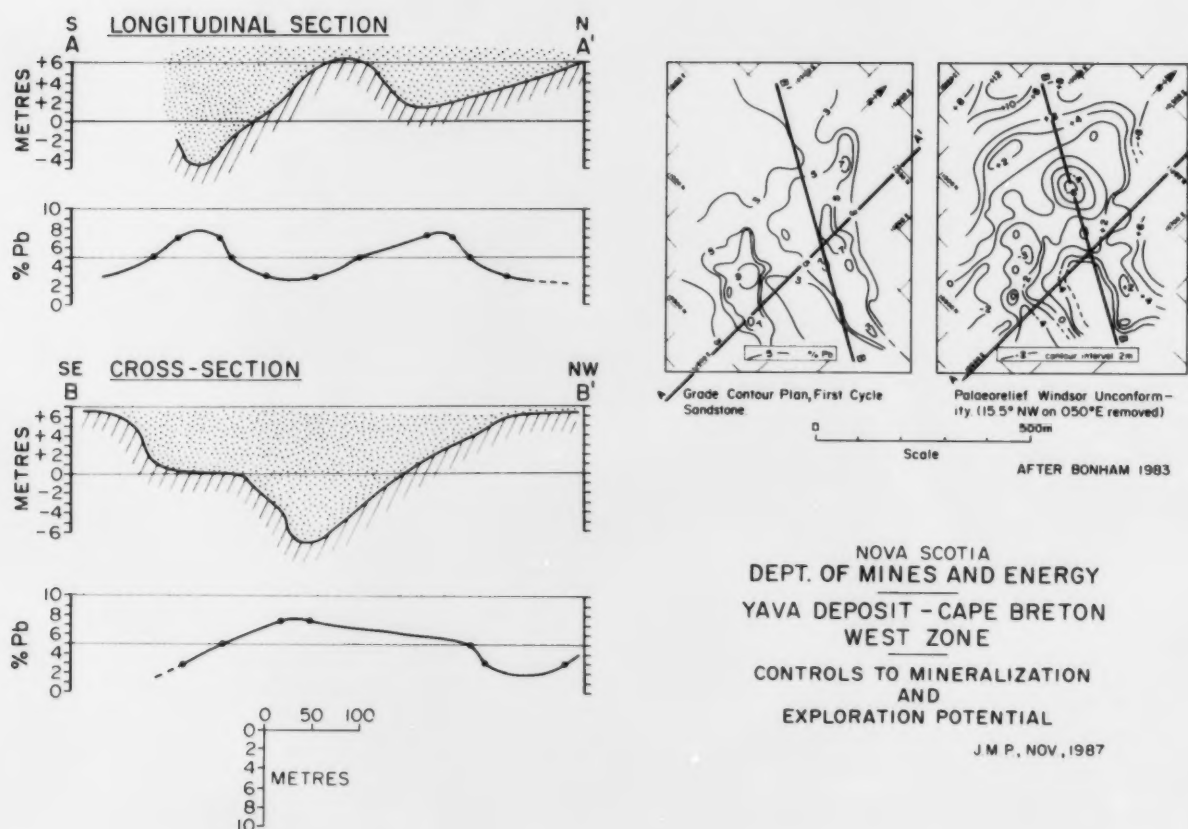


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LITHOSTRATIGRAPHIC, GEOLOGICAL AND PALEOGEOGRAPHICAL SETTING OF CARBONATE BUILDUPS IN THE LOWER CARBONIFEROUS WINDSOR AND HORTON GROUPS, NOVA SCOTIA¹

R. C. Boehner

INTRODUCTION

Studies of carbonate rocks in the Lower Carboniferous of Nova Scotia over the past 60 years have been instrumental in the development of a comprehensive stratigraphic, paleontological and paleogeographical framework for the marine evaporitic Windsor Group (Bell, 1929, 1958; Sage, 1954; Stacy, 1953; Moore, 1967; Schenk, 1969, 1984; Mamet, 1970; Moore and Ryan, 1976; Geldsetzer, 1977, 1978; Ryan, 1978; Kirkham, 1978; Giles and Boehner, 1979; Giles et al., 1979; Giles, 1981; Boehner, 1984; Schenk and Hatt, 1984; von Bitter and Austin, 1984; Utting, 1987). Although volumetrically subordinate, typically less than 15% of the 1000 m thick section, these carbonates have historically been a major source of limestone and dolomite (dolostone) as well as key beds for local and regional correlation. The limestone and dolomite production is used for agriculture and industry, particularly in cement, iron and steel manufacture (e.g. Upper Musquodoboit and Irish Cove). The buildup facies of the Windsor Group carbonate members are especially important because of their purity and thickness. The term buildup is used in a general sense for bodies of carbonate rock that have characteristics of bioherms or reefs and locally form thicker sections in

mounds or banks enclosed to varying degrees within or as lateral facies equivalents of regionally extensive units. The buildups are known hosts for base metal deposits (Gays River) and industrial minerals including celestite and barite (Enon). They may be potential reservoirs for hydrocarbons, although only trace to minor shows are presently known. The buildups, therefore, are important for further exploration and exploitation where they can be identified using various methods including mapping, predictive geological models based on stratigraphy and facies relationships, geophysics and drilling.

This report is a synopsis from more detailed information on carbonate buildups compiled originally as a series of 11 individual case histories for the Canadian Reef Inventory Project, Canadian Society of Petroleum Geologists (Memoir 13, *Reefs in Canada and Adjacent Areas*, in production; see Boehner et al., 1987). The purpose of this report is to supplement as well as integrate the detailed case histories into a more general stratigraphic and paleogeographical perspective.

REGIONAL GEOLOGICAL SETTING

The Maritimes Basin (Roliff, 1962) is the erosional remnant of a complex area of Upper Paleozoic (upper Devonian

¹ Funded by the Canada - Nova Scotia Co-Operative Mineral Program 1981-1984 and the Canada - Nova Scotia Mineral Development Agreement 1984-1989.

to lower Permian) sedimentary rocks in basins, uplifts and platforms underlying 250 000 km² of onshore and offshore Atlantic Canada (Fig. 1). The basin fill is up to 9000 m thick and is dominated by continental alluvial-fluvial-lacustrine rocks with a single marine-evaporitic intercalation, the Windsor Group. The rhythmic character (recognized earlier by Bell, 1929) of the interstratified evaporites (gypsum, anhydrite, halite and potash), redbeds and fossiliferous marine carbonates was described and correlated as a series of major cycles (MC 1 to MC 5; Figs. 2 and 3) and minor or minicycles throughout Nova Scotia by Giles (1982) and Boehner (1984, 1985).

This framework, summarized diagrammatically in Figure 2, coincides closely with litho- and biostratigraphic subdivisions. It avoids the complicated stratigraphic nomenclature, simplifies discussion of broad correlations and forms the basis for illustrating the complex stratigraphic - facies relationships. The relationships shown in Figure 2 are a composite of many localities and are nowhere known to be present in their entirety, due in part to the structurally disturbed nature of these areas.

Approximately 70 buildups have been identified in the area extending

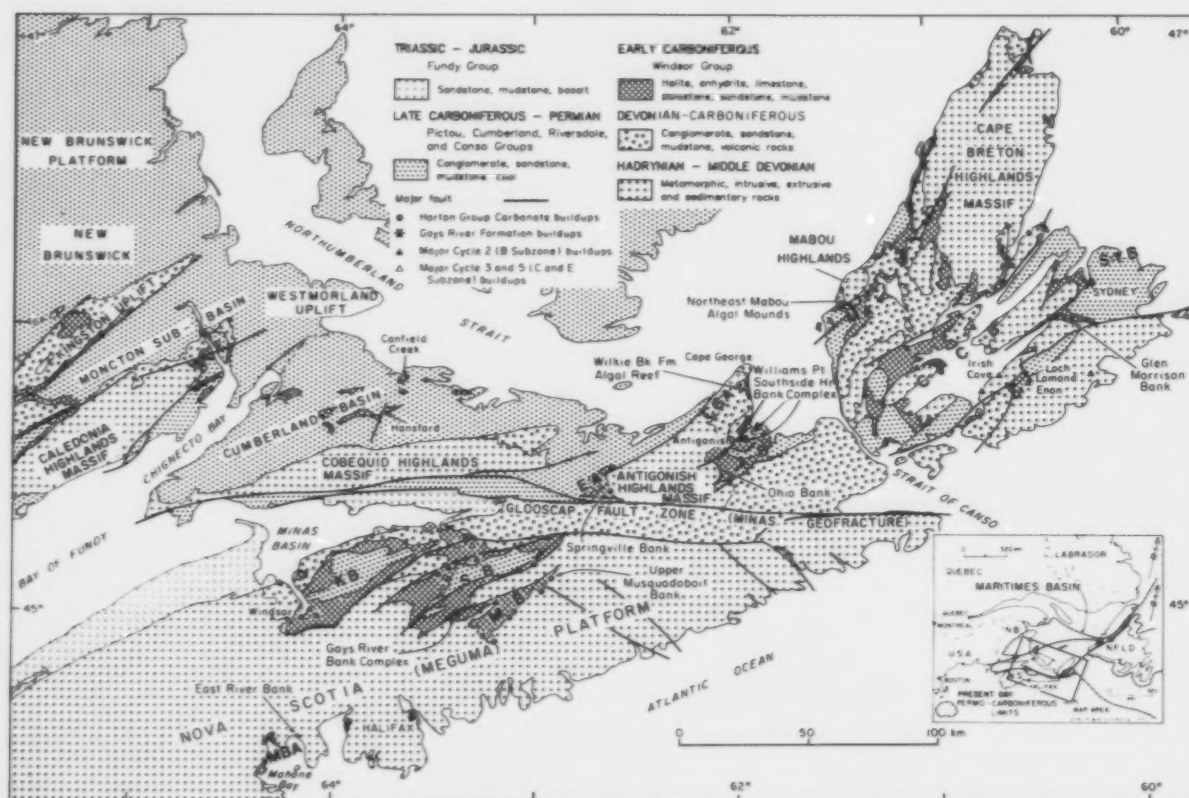


Figure 1. Geological and location map of Lower Carboniferous carbonate buildup localities in Nova Scotia. MBA, Mahone Bay area; MB, Musquodoboit Basin; SB, Shubenacadie Basin; KB, Kennetcook Basin; EA, Eureka area; AB, Antigonish Basin; MA, Mabou area; CCB, Central Cape Breton; SYB, Sydney Basin.

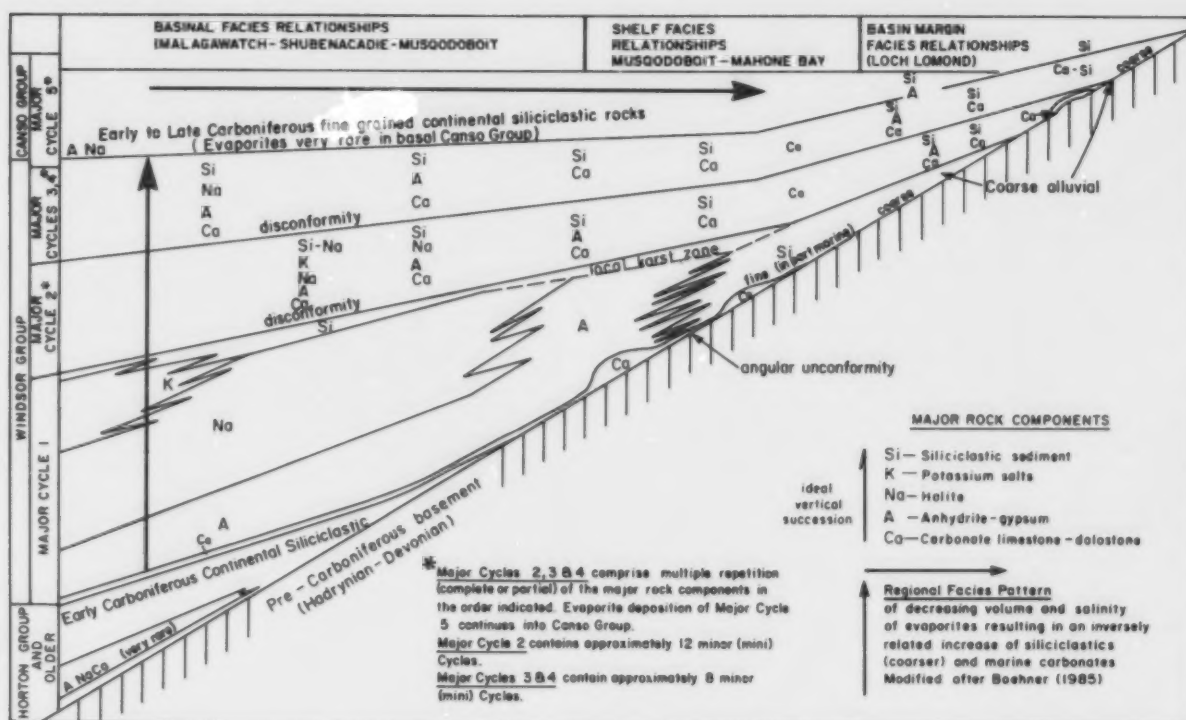


Figure 2. Diagrammatic stratigraphy and facies relationships of Windsor Group Major Cycles and minor cycles in Nova Scotia.

over 350 km from Mahone Bay to Sydney (Fig. 1). These banks and localities may be grouped into 5 stratigraphic intervals, one in the Horton Group and four in the Windsor Group. These, in turn, may be considered within three primary depositional - paleogeographic settings: (1) Horton Group, lacustrine; (2) Windsor Group, onlap basin margin; and (3) basinward (center).

HORTON GROUP BUILDUPS

Buildups within the Horton Group are very rare and highly restricted in areal extent. They have only been recognized and documented in the Wilkie Brook Formation in the Cape George area although minor thin limestone is known regionally. The Horton Group is dominated by continental siliciclastics representing alluvial, fluvial and lacustrine deposition. These environments are not noted for prolific

carbonate deposition, typically they show only thin algal lacustrine and pedogenic limestones. Consequently, the limestone buildup, 'algal reef' and laterally extensive thin limestone horizon of the Wilkie Brook Formation, as currently documented, are considered to have limited resource potential. They may reflect, however, more widespread lacustrine deposition in deeper untested areas.

WINDSOR GROUP BUILDUPS

MAJOR CYCLE 1 BUILDUPS

Carbonate buildups in the Windsor Group, in contrast, are widely distributed and relatively numerous. Approximately 40 banks or localities have been identified as buildup facies at the base of Major Cycle 1 within the Gays River Formation. The banks are best developed in areas where Major

Cycle 1 oversteps the Horton Group and rests directly on the pre-Carboniferous basement unconformity. These areas are inferred to represent a paleogeographic setting of paleotopographic highs including isolated knobs (inselbergs), hills and ridges (cuestas) both within and marginal to the interconnected basins. The buildup association with paleotopographic highs is probably influenced by a series of interrelated factors including: (1) substrate-solid and clean; (2) bathymetry - water depths within the photic zone; (3) chemistry - evidence of early salinity increase, vertical and(or) horizontal salinity stratification, local and regional; (4) clastic sedimentology-terrigenous clastic input and distribution; (5) paleogeography-basin configuration reflecting physical oceanography and energy conditions (currents and wave exposure); and (6) the merits and applicability of an innovative idea advanced by von Bitter et al. (1988) that hydrothermal-exhalative related 'vent communities' were important in mound localization and development.

These buildups have a broad range of dimensions, which frequently are not clearly defined but generally may be up to >50 m (20-25 m average) thick, and form complexes several kilometres long and approximately 1 km wide. Individual banks have variable mound to wedge geometry with lateral extents in the range of hundreds of metres. Their composition is highly variable and the relationships with related facies, including evaporites, siliciclastics and correlative carbonates is complex and subject to diverse interpretations. Examples of complex relationships involving contemporaneous deposition with siliciclastics (fine grained marine to marginal marine and coarse alluvial) and evaporites include (1) the Meaghers Grant Formation in the Musquodoboit Basin and the Sydney River Formation in the Sydney Basin and (2) thin carbonate interbeds in the basal anhydrite of MC 1 (Carrolls Corner

Formation and Bridgeville Formation) that (a) are similar to some of the algal facies of the Gays River Formation and Macumber Formation or (b) contain carbonate detritus derived from living or dead Gays River Formation banks which may represent multiple reactivated deposition on pre-existing mounds.

MAJOR CYCLE 2 BUILDUPS

The relatively large size and widespread nature of Major Cycle 1 buildups are not apparent in Major Cycle 2. Following deposition of the vast volume of evaporites in MC 1 the depositional setting (paleotopography, bathymetry) was radically changed. The post-Horton Group topography was effectively levelled, resulting in very gentle depositional slopes. This favoured, with eustatic and(or) tectonic driven sea level fluctuation, widespread transgressive - regressive deposition of marine carbonates, evaporites and redbeds in numerous minicycles. This style of sedimentation prevailed throughout the remainder of Windsor Group deposition in Major Cycles 3, 4 and 5 (subzones C, D and E). Approximately 25 buildups have been identified and are assigned here to Major Cycle 2. Two principal depositional - paleogeographic settings are recognized: (1) five buildups in a basin margin where MC 2 oversteps MC 1 and onlaps basement, similar to the Gays River Formation situation; (2) twenty buildups in a basinward setting where isolated mounds are developed without obvious basement-paleotopographic control.

The buildups are volumetrically rare in comparison to their correlative off-mound facies. The basinward mounds are problematic because the factors controlling their localization and development are not well defined. Prediction of their occurrence in the subsurface is based on conventional geological data and is consequently very difficult. Factors which may have

been important in their initiation and development are apparently subtle and could be related to: (1) slight topographic anomalies (highs or lows); (2) localized hard substrate, hardground and subsea cementation; (3) favourable circulation or current patterns and elevation above turbid water. The mounds appear to be dominated by *in situ* organisms and lack evidence for a prevalent mechanical wave or current concentration origin except in the case of the basin margin facies. Any small anomaly in the above factors may have been critical in the establishment of the initial organic (skeletal) communities. The laterally extensive correlative facies are typically dark, organic-rich shaly carbonates with high siliciclastic content (10s of %). The mounds, in contrast, are relatively clean with <10% siliciclastics.

The basinward mounds are typically convex upward with a flat to slightly convex base and are 3-4 times the thickness of the normal facies. The mounds have dimensions of 100-200 m laterally and thicknesses of 15-20 m. Basin margin buildups have more complex geometry subject to original depositional influence of wave and current action. The extent to which the presently identified distribution and number of localities reflects their actual abundance is not clear. Limited outcrop and subsurface data, often localized near basin margins, may bias the interpreted distribution patterns.

MAJOR CYCLE 3 BUILDUPS

Five carbonate bioherms have been identified in the upper part of the Windsor Group: two in the Herbert River Limestone Member at the base of Major Cycle 3 (C subzone); and three in the Kennetcook Limestone Member, Major Cycle 5 (E subzone). To date, the buildup facies has only been identified in the basinward setting. Where the E₁ Limestone (MC 5) onlaps basement near Loch Lomond (Figs. 1 and 3) biohermal

skeletal facies are apparently not developed. Buildup dimensions are poorly defined but appear to be similar to those in Major Cycle 2 with lateral extent of 100 m and thickness of up to 20 m. Their geometry, although similar to buildups of MC 2, differs in one respect: the MC 3 and 5 buildups occur as locally developed skeletal-biohermal mounds within, and facies equivalent to the normal marine carbonate. The thicknesses of both facies are similar and the biohermal mounds are enveloped within the normal facies, in contrast to the distinctive, separate, thickened mounds developed in MC 2.

CONCLUSIONS

Carbonate buildups are very rare in the Horton Group and are most numerous and best developed in the marine evaporitic Windsor Group. They are widely distributed through Nova Scotia occurring in varying numbers in most Carboniferous basins. The notable exception is the Cumberland Basin where buildups are virtually unknown with only possible localities near Hansford and Canfield Creek (see Boehner, 1988). Although their distribution and frequency patterns are distorted and biased to varying degrees by the minimal to inconsistent outcrop and drilling data, several general patterns may be recognized. The most numerous and probably the largest buildups are the individual banks and bank complexes of the Gays River Formation. These represent marine carbonate deposits of the initial Visean marine transgression in Major Cycle 1 of the Windsor Group. Pre-Windsor Group paleogeography and paleotopography were major factors in the development of the buildups. Basin infilling by the evaporites of MC 1 radically changed the subsequent depositional setting. The pattern of buildup distribution and morphology accompanying the trend of basin expansion was modified such that buildups were developed in a basinward setting without obvious

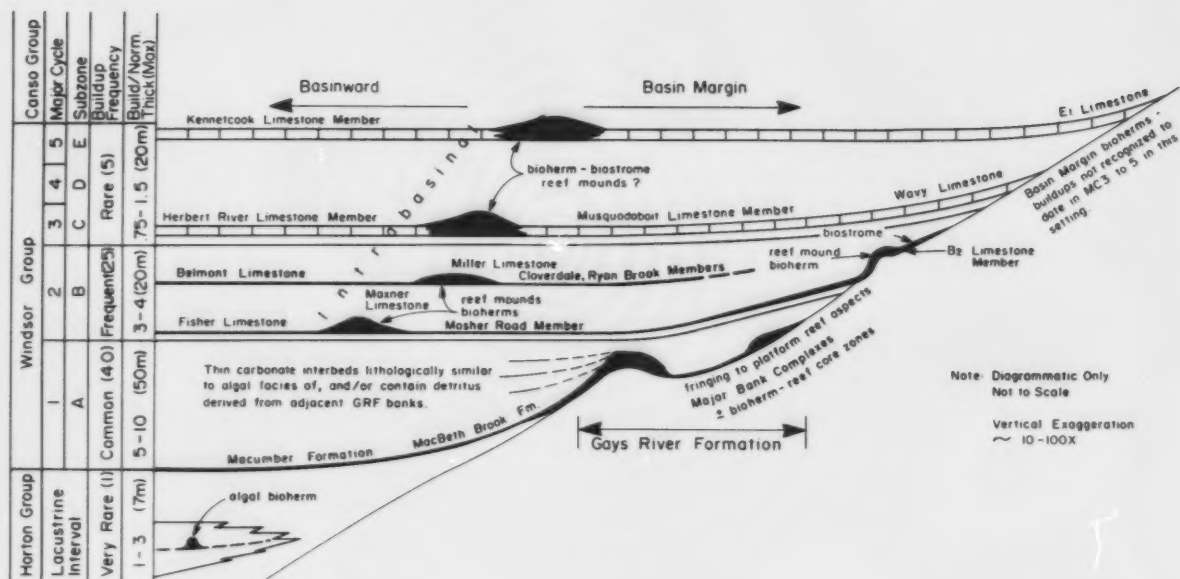


Figure 3. Stratigraphic distribution of Lower Carboniferous buildups in Nova Scotia.

paleotopographic control as well as along the basement unconformity near the expanded basin margin. The basinward setting has not been recognized to date in the Gays River Formation. The buildups in the upper part of the Windsor Group, Major Cycles 3 and 5, are relatively rare and appear to have modified morphology reflecting changing depositional environment and setting. In contrast to the distinctive mound form with thin off-mound (normal) facies in the basinward buildups of MC 2, the buildups in MC 3 and 5 appear to be bioherms enveloped within or only slightly thicker than the off-mound (normal) facies. The normal facies in MC 3 and 5 away from the bioherms are much thicker (3-5x) than the normal facies in MC 2.

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PRELIMINARY REPORT ON WINDSOR GROUP STRATIGRAPHY AND CORRELATION IN THE CUMBERLAND BASIN, NOVA SCOTIA¹

R. C. Boehner

INTRODUCTION

The stratigraphy and correlation of the Windsor Group in the Cumberland Basin has been problematical for several reasons: (1) Windsor Group rocks outcrop in and adjacent to structurally complex, en echelon diapiric anticlines and several isolated diapiric bodies (Fig. 1); (2) exposures of these relatively incompetent rocks are generally limited, represent only small portions of a potentially thick succession and are locally extensively modified by karstic processes; and (3) uncertain relationships to poorly exposed and complexly folded diapiric evaporites in the lower part of the succession. In addition to these problems of exposure and deformation, significant facies changes (vertical and lateral) to sections without diagnostic marine rocks compound the other difficulties.

Understanding and documenting the stratigraphic succession is very important to realizing the maximum mineral potential of these rocks. The Windsor Group is the primary source of salt in Nova Scotia. Currently there are 2 mining operations, a conventional underground mine at Pugwash (Fig. 1) operated by the Canadian Salt Company Limited (recent annual production approximately 800 000 tonnes) and a brining evaporation plant at Nappan operated by the Domtar Chemicals Group, Sifto Salt Division (recent annual

production approximately 65 000 tonnes). Historically, gypsum has been produced from small operations at Nappan and Amherst Point, and limestone and dolomite have been quarried at Limekiln Brook and Pugwash. Red shale and siltstone were used for brick manufacture at Pugwash, minor celestite has been extracted at Beckwith and small quantities of potash were produced at Malagash, which was the location of the first underground salt mine in Canada (1918-1959). Most of these commodities are also principal rock types of the Windsor Group making the entire stratigraphic succession a target for potential economic mineral deposits. In addition, native sulphur (Carter et al., 1987), hydrocarbons and base metals are known to be associated with the Windsor Group elsewhere in Nova Scotia.

PREVIOUS WORK

The first detailed examination of the stratigraphy and correlation of the Windsor Group in the Cumberland Basin area is documented in maps and reports by geologists working for Imperial Oil in the area of the Minudie Anticline near Amherst (Imperial Oil Limited, 1931; Wright et al., 1931; Roliff, 1932). Subsequently, Bell (1944, 1958) described in detail the stratigraphy and paleontology of the 3 best exposed Windsor Group limestone sections at Pugwash (Dewar Hill Quarry), Limekiln Brook and Lower Maccan (locations 7, 5

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

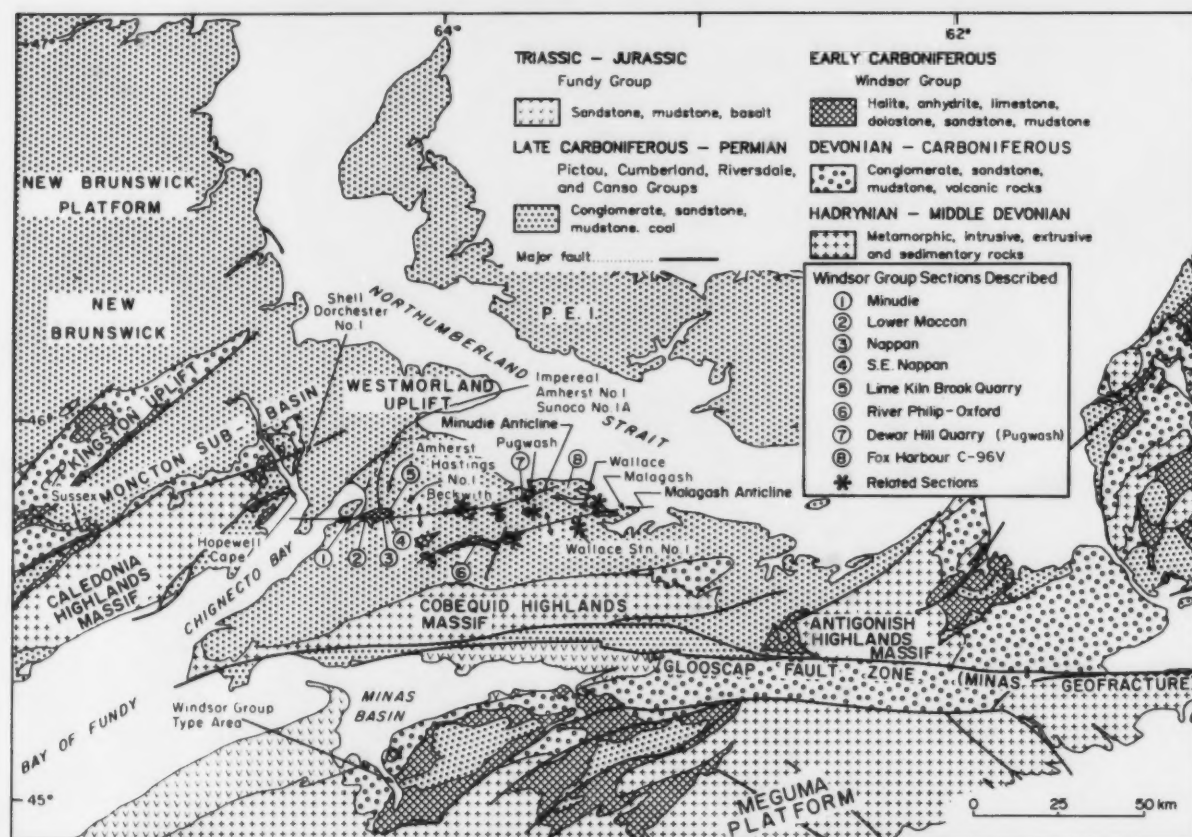


Figure 1. General geology and Windsor Group stratigraphic section location map, Cumberland Basin, northern Nova Scotia.

and 2; Figs. 1 and 2). Detailed descriptions of the stratigraphy of the evaporites in the lower part of the section dealt only with the complexly folded section in the Pugwash Mine (Evans, 1972; Carter 1987). A reasonably complete stratigraphic column for the Windsor Group in the Cumberland Basin has not been previously established, precluding correlation with the lithostratigraphic Major Cycle framework of Giles (1981) and Bohner (1985).

STRATIGRAPHY AND CORRELATION

MAJOR CYCLE 1

Because of the configuration of the Cumberland Basin, with marginal

onlap of post-Windsor Group Carboniferous rocks, Windsor Group strata do not outcrop around any part of the perimeter of the Cumberland Basin in Nova Scotia. The lowermost parts of the Windsor Group are inferred to be represented by the contorted evaporites (salt, anhydrite, gypsum and potash) and redbeds in the central cores of diapiric structures. Part of this lowermost interval of the Windsor Group is probably intersected in the lowest 400 m of borehole PFH C-96V (Fig. 3). This complex section was intersected in other deep drillholes (Fig. 1), including Imperial Amherst No. 1 and Sunoco No. 1A at Nappan where the base of the Windsor Group is in fault contact with Upper Carboniferous rocks (Bohner, 1986). Only one

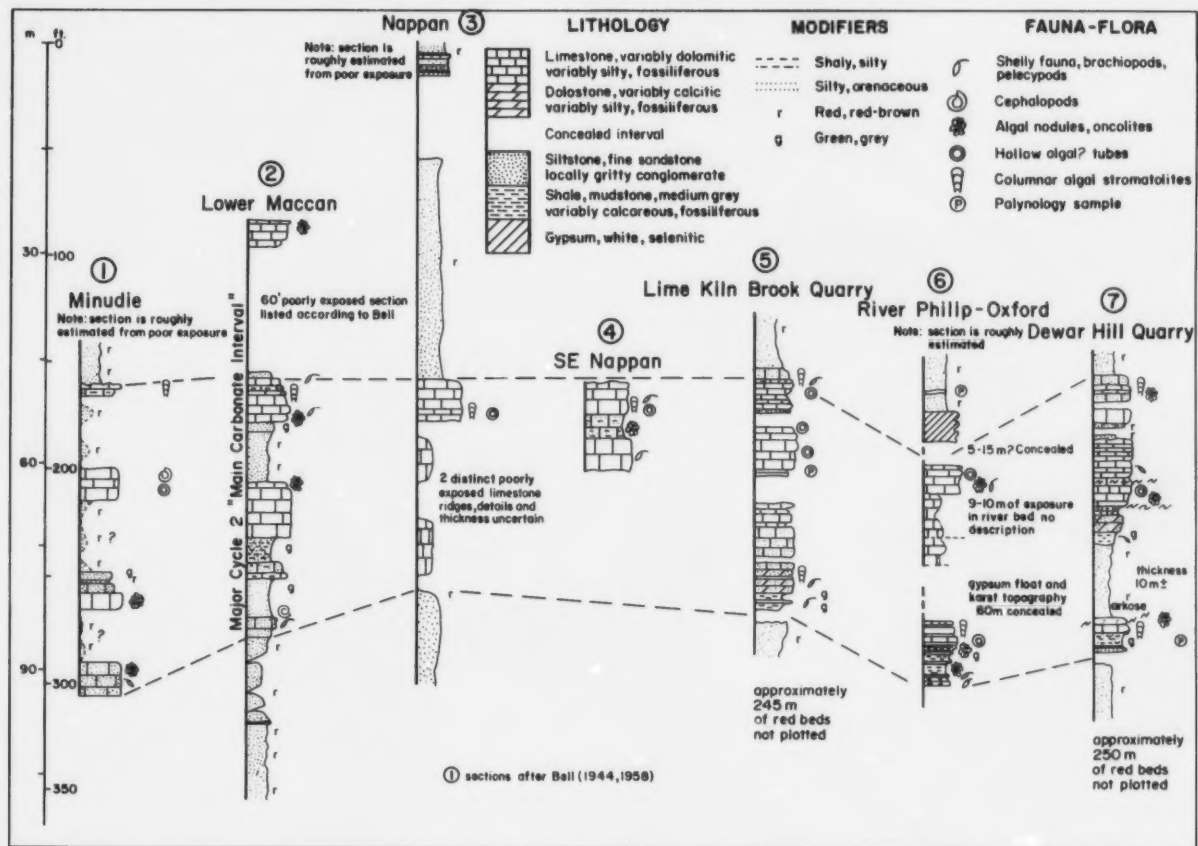


Figure 2. Stratigraphy and correlation of the main carbonate interval in the middle part of the Windsor Group (B-Subzone, Major Cycle 2), Cumberland Basin, northern Nova Scotia (Localities 1 to 7, Figure 1).

exploration borehole, Anschutz Wallace Station No. 1, could possibly have penetrated to the stratigraphic base of the Windsor Group. This hole, drilled on the crest of the Malagash Anticline near Wallace (Fig. 1), was abandoned after numerous drilling problems in what was interpreted as Horton Group at a depth of 4536.9 m. The section in the lowest part of the drillhole is problematic in several respects. That section, interpreted to be the basal part of the Windsor Group, is a cherty-siliceous grey shale (MacDonald, 1973). Thus, the regionally extensive basal carbonate of the Windsor Group (Macumber or Gays River Formation) is apparently not represented in the Cumberland Basin, nor is the equally

extensive basal anhydrite (typically 100-400 m thick). Identification of the Horton Group (4267-4536.9 m) was partially based on the presence of arkosic sandstone and fine conglomerate; these rock types also occur within Windsor Group sections exposed in the Cumberland Basin. Paleontological results were inconclusive. The interpretation of 'Horton Group' salt in the interval 4432-4536 m is questionable, as there is no apparent geophysical response typical of salt in the gamma ray and sonic logs run in the interval. Salt chips recovered may equally represent caved or plucked material from higher in the well. In summary, data to support the interpretation of the

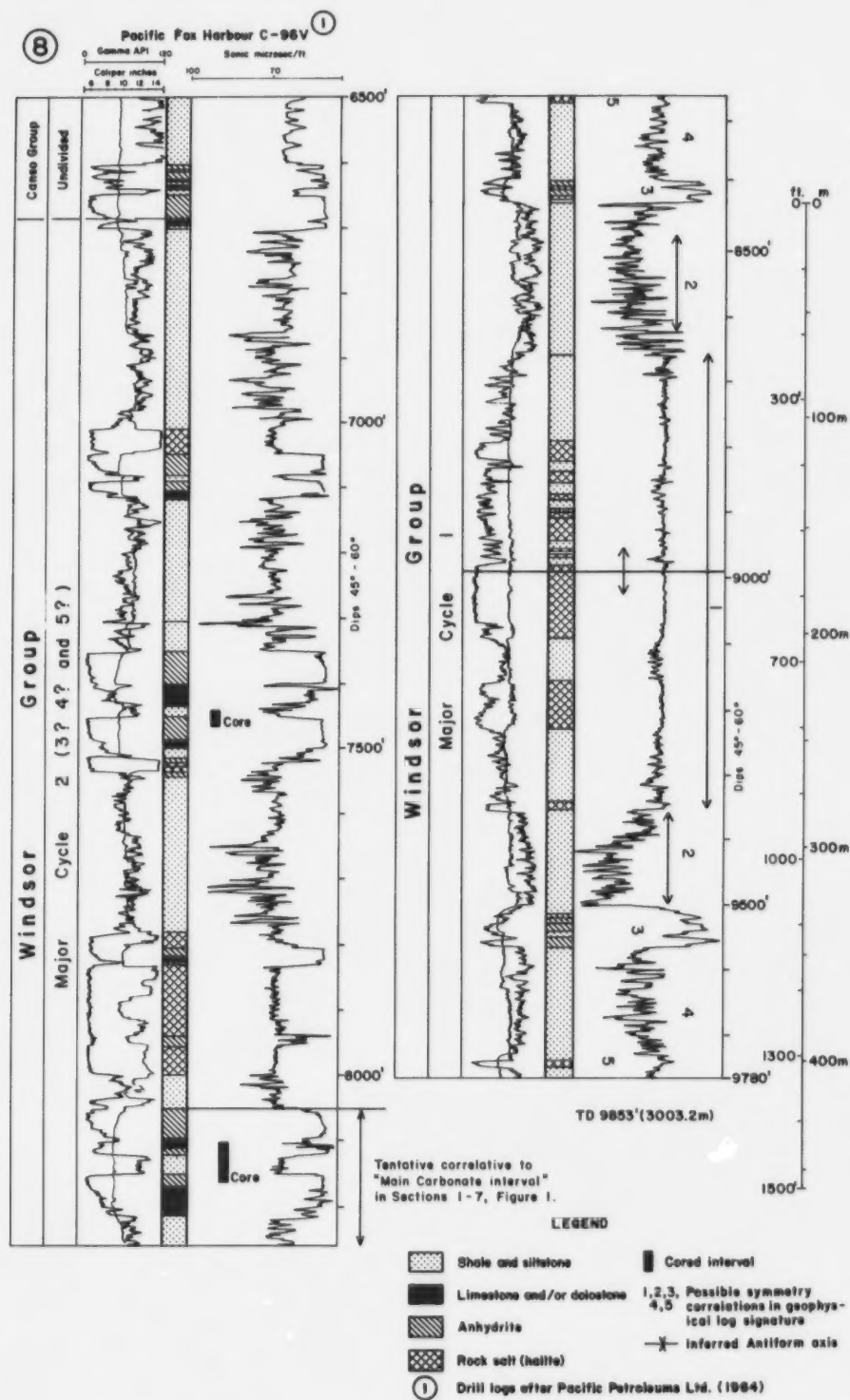


Figure 3. Windsor Group stratigraphy in Pacific Fox Harbour C-96V well, Fox Harbour, Cumberland Basin (Locality 8, Figure 1), Nova Scotia.

interval from 4267-4536.9 m as Horton Group are inconclusive, therefore the Wallace Station No. 1 drillhole may have been abandoned within the Windsor Group. If this is true, then the base of the Windsor Group has not been intersected anywhere in the Cumberland Basin in Nova Scotia. The nearest possible correlative section of Horton Group-Macumber Formation - basal anhydrite (Fig. 4) may be in Shell Dorchester No. 1 (Fig. 1) drilled near Dorchester, New Brunswick (drillhole log in Hamilton, 1961).

The stratigraphy of higher parts of Major Cycle 1 may be represented in the well documented succession within the Pugwash Mine. Evans (1972) described a stratigraphic section approximately 240 m thick (top uncertain) comprising complexly folded, interstratified, grey-brown and locally carnallitic muddy salt and anhydrite in rafted, boudinaged beds locally exceeding 30 m in thickness. This stratigraphic sequence was modified by Carter (1987) who determined younging directions, reordered the stratigraphic position of Evans' (1972) two anhydrite units ('shaft' and 'borate') and recognized a new anhydrite member ('third anhydrite') in contact with siliciclastics near the top of the section on the flanks of the diapir. Evaporite-dominated sections within the Windsor Group diapiric evaporite core zone with similar general lithology (Figs. 2 and 4), but as yet uncertain internal stratigraphy, are present in diamond-drill holes at Nappan (Domtar Ltd., DN-5A, DN-6) and Oxford (Amax Exploration, AOP-1 and AOP-2). The precise stratigraphic assignment of the Pugwash Mine section is not yet clear although it is here tentatively assigned to the middle to upper part of Major Cycle 1 above the basal anhydrite.

The contact between the evaporite-dominated Major Cycle 1 and the younger, redbed-dominated Windsor Group section (Major Cycle 2 and younger) is

not known to be exposed or preserved intact in the Cumberland Basin. The relationship typically appears to be structural, that is intrusive and(or) faulted, and complicated by solution collapse. Sections that possibly document this interval are very rare. The inferred contact in borehole PFH C-96V, if not structurally disrupted, indicates that a major interval dominated by redbeds occurs near the top of Major Cycle 1 (Fig. 4). This would be consistent with the presence of a thick section of redbeds beneath the lowermost Major Cycle 2 limestone beds at Limekiln Brook (250 m according to Bell, 1944) and the Dewar Hill Quarry near Pugwash (245 m according to Bell, 1944). Drilling in this complicated zone near the Dewar Hill Quarry by Canadian Salt Company (CRSC-58) indicates a complex mixed salt-redbed section with minor potash and steep dips to a depth of 321 m. An additional stratigraphic section or a contact with the diapiric evaporite core cannot be confirmed in this drillhole. Similarly, outcrop exposures and shallow holes drilled near Nappan by Imperial Oil Ltd. (IN 1, 5, 7 and 9) confirm a section of redbeds including fine conglomerate between the diapiric evaporite core and the limestone section of Major Cycle 2 documented along the southern border of the Minudie Anticline.

Paleontological dating of the Major Cycle 1 section has been inconclusive. Palynology samples from the Pugwash Mine and the Nappan area yielded assemblages typical of the Windsor Group (Dolby, 1987) but were of insufficient quality and quantity to confidently establish the position in the lower part of the Windsor Group. Stratigraphic position and gross lithology, although not unique attributes, provide the main criteria for the assignment of these complex rocks to Major Cycle 1. It is interesting to note that redbeds at the top of Major Cycle 1 (Figs. 2 and 3) approximate the inferred position of

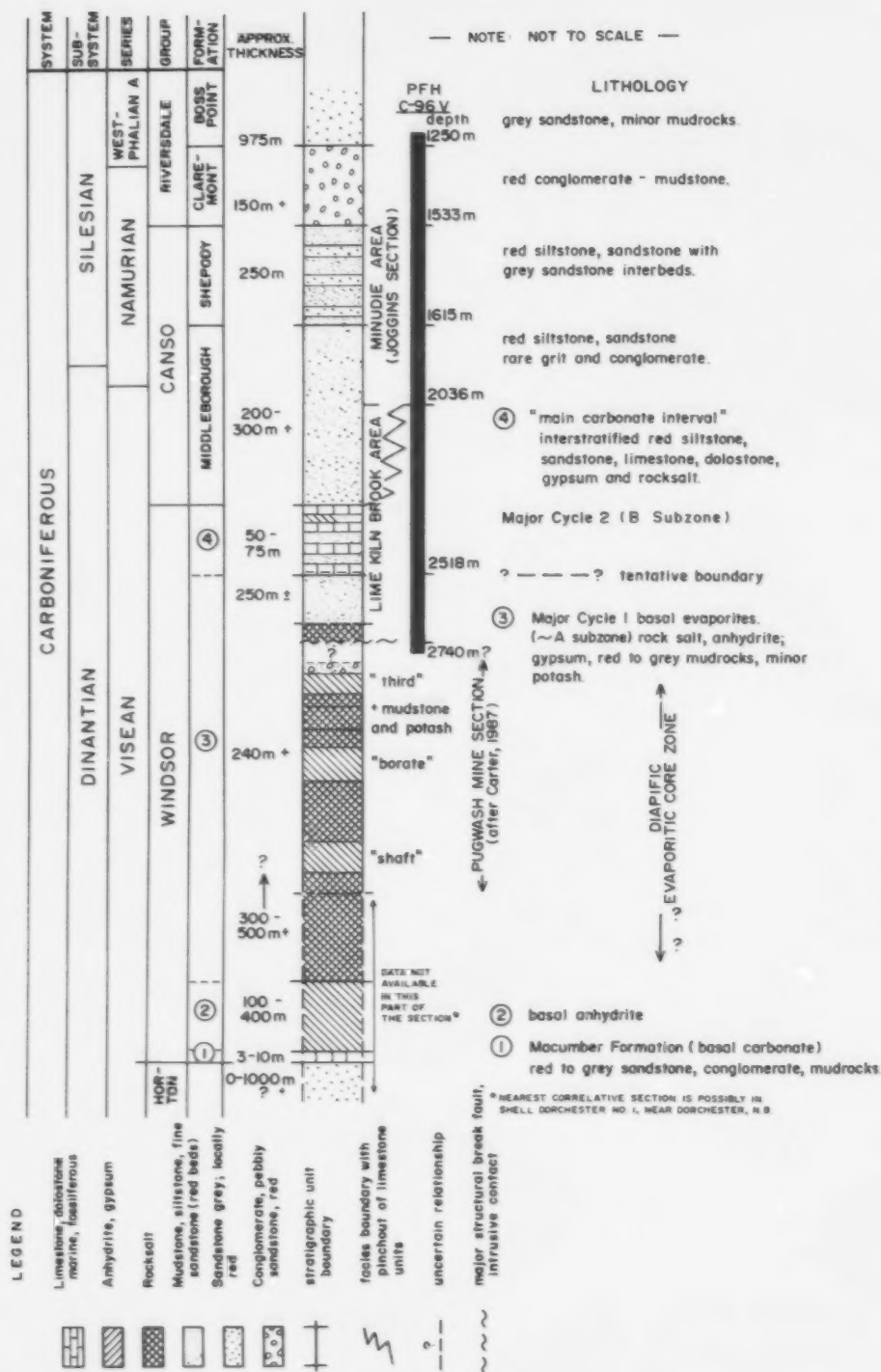


Figure 4. Diagrammatic composite stratigraphy of the lower Carboniferous with emphasis on the Windsor Group, Cumberland Basin, Nova Scotia.

the Tennycap Formation in the Windsor Group type area (Giles, 1981) and the Cloverhill Formation in the Sussex area of New Brunswick (McCutcheon, 1981). Large scale fold repetition of the Major Cycle 1 section (Fig. 3) is suspected in the interval from 2518-3003.2 m (8260 - 9853 ft.). The inferred repetition is based on the broad symmetrical pattern of the geophysical log signatures and general lithology about a hypothetical antiform axis at a depth of approximately 2735-2740 m (8000 ft.). Five zones of symmetry are identified on Figure 3: (1) a broad interval of rock salt and siltstone-mudstone with a general trend of decreasing salt upward and downward; (2) an interval of mudstone with erratic, decreasing velocity with depth on sonic and gamma ray signatures; (3) a distinctive triplet of anhydrite beds; (4) a mudstone interval similar to (2) but less irregular; and (5) an isolated rock salt interval. This symmetry is suspicious but not unique or conclusive. The scale and style of fold repetition about horizontal to vertical fold axes has, however, been well documented in several deformed Carboniferous basins (Boehner, 1986).

MAJOR CYCLE 2

The stratigraphy and correlation of Major Cycle 2 and younger strata exposed at surface are generally less complicated because these rocks are apparently less disrupted than the diapiric evaporite section of Major Cycle 1. The base of Major Cycle 2 has been tentatively placed at the base of the main carbonate interval which generally has a fossiliferous, basal calcareous shale to shaly limestone in the lower parts of the 6 relatively complete limestone-bearing sections (1-7, Fig. 2) between Minudie and Dewar Hill Quarry.

Despite the distinctive appearance of specific carbonate members in outcrop it is not possible to precisely correlate the Major Cycle 2 sections 1-

7 in Figure 2 into the PFH C-96V drillhole. This is due to uncertainties related to chip logs and geophysical log responses to the specific carbonate members and because of possible fold repetition in subsurface sections. At best, using general lithological character, a possible correlative interval is chosen from 2454 - 2518 m (8050 - 8260 ft.). In view of possible repetition in Major Cycle 1 in PFH C-96V (Fig. 3), specific correlation of the Major Cycle 2 section is considered tentative. The vertical relationships of minor cycle lithological components, however, are consistent with a normal right way up pattern. Although no clear symmetries of lithology or geophysical log response patterns indicative of repetition are apparent, the presence of repetition in the Major Cycle 2 section has not been eliminated.

The stratigraphic sections, general correlations and biostratigraphic age (revised after Moore and Ryan, 1976) of sections 1-7 (Fig. 2) were delineated by Bell (1944, 1958) and have been confirmed and refined in this study. Variations are present and incomplete exposure of some sections remains a hindrance to more precise correlations. The main carbonate interval of Major Cycle 2 is characterized by an interstratified succession of at least 3 and probably 4-5 separate limestone - dolostone horizons. These are generally separated by redbeds (siltstone, sandstone and locally fine conglomerate) and the occurrence of gypsum is indicated by sinkholes near lower Maccan and outcrops in the River Philip-Oxford area. Gypsum and anhydrite appear to be more extensive in the subsurface but are largely removed by karst processes in near surface and outcrop areas. The basal part of the section is marked by a 10-25 m thickness of calcareous grey shale with abundant marine fauna and flora. Distinctive columnar algal stromatolites form the principal

lithofacies of the first marine carbonate and are well exposed at Dewar Hill Quarry (section 7). Carbonates of the interval constitute one or more zones of variably silty limestone, typically dense, hard and crystalline, and irregular nodular-oncolitic (1-10 cm) limestone near contacts. Distinctive hollow algal(?) tubes 1-1.5 cm in diameter and 3-6 cm long are ubiquitous in the limestone. The upper part of the main carbonate interval is generally marked by a columnar algal stromatolite unit with a distinctive tilted growth form which makes an axial angle of 45-60° to the bedding plane.

Details of the stratigraphy of overlying marine carbonate units are generally unclear. Thin, poorly exposed carbonate units are known at Nappan (section 3), Lower Maclean (section 2) and perhaps at the top of the Dewar Hill Quarry near Pugwash (Fig. 2, section 7) where 2 or 3 carbonate units in a complex section are not yet fully documented. The section thickness for the main carbonate interval is approximately 50-70 m. Outcrops in the Minudie to Limekiln Brook Quarry area are relatively common and appear to be reasonably complete, without apparent major structural disruption. Fine grained redbeds that dominate the overlying section have a thickness of not less than 300 m and are part of the Middleborough Formation (Canso-Windsor Group). The thickness of the Middleborough Formation compares favorably with what is considered to be the correlative section above 2454 m (8050 ft.) in drillhole PFH C-96V (Fig. 3).

GENERAL CORRELATION

Placement of the Windsor Group-Canso Group boundary (Fig. 4) has historically been a problem in the Cumberland Basin, especially in the Minudie-Nappan area. Bell (1944, 1958) placed the base of the Middleborough Formation, which is considered the base

of the Canso Group in the Cumberland Basin, at the top of the highest carbonate unit in the main carbonate zone. The contact was first interpreted as conformable by Bell (1944) but later as disconformable (Bell, 1958). Problems faced by the stratigrapher/sedimentologist addressing this boundary can be expressed as follow: (1) what happens to the rest of the B-subzone and Upper Windsor Group limestone members (numbering more than 10) that are well documented elsewhere in Nova Scotia? (2) how to define the boundary when the Windsor Group undergoes facies change involving the pinch-out of the diagnostic marine limestone members, especially early in the depositional history? and (3) the redbeds of the Windsor Group and Canso Group are apparently indistinguishable, making any lithostratigraphic separation arbitrary.

This problem is not unique in Nova Scotia. Keppie et al. (1978) faced a similar situation and proposed a definition of the Windsor Group that placed the top of the Group at the top of the stratigraphically highest marine stratum. This was further specified to be a marine carbonate by Giles (1981). Using this approach, the boundary definition is relatively straight forward as long as undocumented, stratigraphically higher marine strata, specifically carbonates, are not encountered later. The nonmarine redbeds, even though they are facies and age equivalents of the Windsor Group above the limits imposed by the marine strata, are given separate lithostratigraphic status and in the Cumberland Basin are included in the Middleborough Formation (Canso Group; Fig. 4). In New Brunswick, the name Hopewell Group has been applied to this nonmarine interval of the Carboniferous section dominated by coarse to fine redbeds (late Visean to early Westphalian) overlying distinctive marine Windsor Group (or basement) and underlying grey sandstone of the Boss

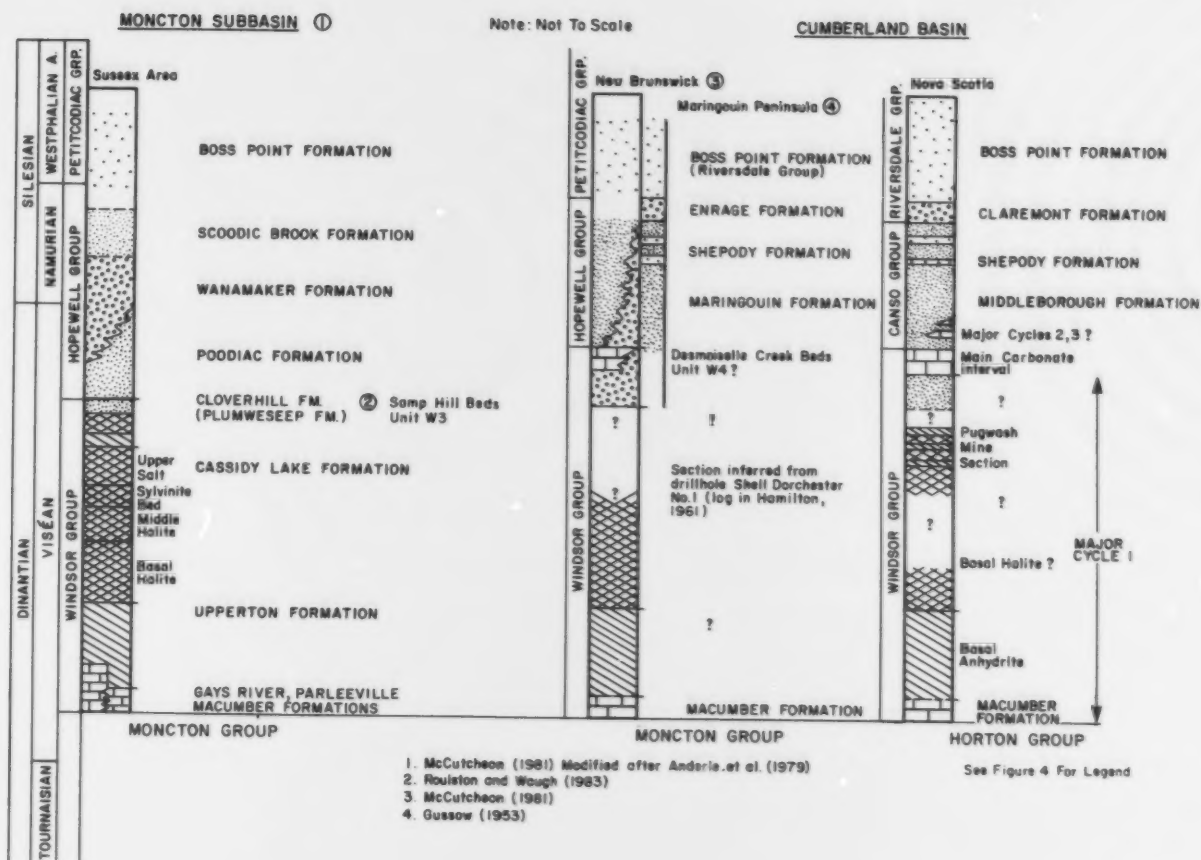


Figure 5. General correlation of Visean-Namurian strata (with emphasis on the Windsor Group) in the Cumberland Basin and Moncton Sub-basin.

Point Formation (Fig. 5). The Hopewell Group, therefore, may be age and facies equivalent with all or part of the Windsor Group (upper), Canso Group (all), and Riversdale Group (lower). If applied in the same sense to the Cumberland Basin stratigraphy in Nova Scotia (Figs. 4 and 5) the Hopewell Group would include (be correlative with) units identified as the Middleborough, Shepody and Claremont Formations.

The main carbonate interval of the Windsor Group (Fig. 2, sections 1-7) is very similar to and probably correlative with the Demoiselle Creek beds described in the Hopewell Cape

area of southern New Brunswick by McCutcheon (1981). At Hopewell Cape, McCutcheon (1981) described a 30 m thick section of Lower Windsor rocks (subzone B) with two thin grey units comprising variably siliciclastic, oncolitic, stromatolitic limestone, separated by a thick central unit comprising polymictic conglomerate, sandstone and minor mudstone. Underlying strata, although very poorly exposed, are fine- to medium-grained redbeds. This stratigraphy is generally similar to the situation in sections 1-7. The overlying strata are primarily coarse grained conglomerates assigned to the Hopewell Group whose detailed age and stratigraphic

relationships to Upper Windsor Group or Canso Group are uncertain. A precise correlation with the finer grained Middleborough Formation in Nova Scotia consequently cannot be established.

The relative stratigraphic position, general lithology and probable age similarity indicates the Middleborough Formation is probably correlative with all or parts of the fine grained redbeds of the Hopewell Group including the Maringouin Formation in the extension of the Cumberland Basin in southern New Brunswick as well as the Poodiac Formation of Anderle et al. (1979) in the Sussex area of south-central New Brunswick (Figs. 1 and 5). These finer grained units are apparently the basinward facies equivalents of coarser basin margin facies, including undivided coarse grained Hopewell Group and Wanamaker Formation according to McCutcheon (1981). Similar but as yet unclear documented coarse facies of this age (middle-late Visean?-Namurian) may occur in Nova Scotia in the vicinity of the northern and eastern parts of the Cobequid Highlands (Millville conglomerate?, Falls Formation?).

Marine carbonates and evaporites typical of Major Cycles 3-5, although widespread in Nova Scotia (Giles, 1981), are not recognized and apparently not present in the Cumberland Basin or in southern New Brunswick. A profound facies change, probably reflecting regional paleogeography, is indicated whereby the middle to upper parts of the Windsor Group (Major Cycles 2-5, B-subzone to E-subzone) are restricted in lateral extent or not present in northern Nova Scotia and probably most of New Brunswick. Continental redbeds apparently dominated deposition throughout the late Visean and Namurian to the early Westphalian in this tectonically active area of the Maritimes Basin.

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PENNSYLVANIAN SEDIMENT DISPERSAL TRENDS IN THE CUMBERLAND BASIN OF NORTHERN NOVA SCOTIA¹

R. J. Ryan, J. H. Calder and R. C. Boehner

INTRODUCTION

The Cumberland Basin of northern Nova Scotia and southeastern New Brunswick contains Pennsylvanian strata which, in descending order, comprise the Pictou, Cumberland and, in part, Riversdale Groups (Fig. 1). Throughout much of the basin these Upper Carboniferous rocks overlie Lower

Carboniferous strata. The Cumberland Group of Westphalian A-C (Hacquebard and Donaldson, 1964; Dolby, 1987) and Pictou Group of Westphalian C - Lower Permian (Barss and Hacquebard, 1967) age, form the uppermost exposed rocks over most of the basin. Older basin-fill strata are exposed adjacent to basin margin massifs or intra-basinal diapiric anticlines. These anticlines formed in response to diapirism (halokinesis) of Lower Carboniferous evaporites of the Windsor Group.

PALEOCURRENT MEASUREMENT AND ANALYSIS

The most important factor in the proper use of paleocurrent studies is the reliability of the primary sedimentary structure measured. This is governed to a large degree by the extent to which the structures are exposed in outcrop. Allen (1966) and Miall (1974) indicate the directional variance of the paleocurrent indicator increases with decreasing scale of the flow indicator. Miall (1974) outlined a ranking system for current indicators for modern streams with low rank numbers (i.e. 1, 2) assigned to low variance paleocurrent indicators and high rank numbers (i.e. 5, 6) assigned to high variance paleocurrent indicators. Ranks 1 to 3 represent active river systems, meander belts and major channel reaches within the meander belts, respectively. Minor channels and large sediment bars are rank 4. Rank 5 includes large-scale trough and planar cross stratification.

AGE		GROUP
CARBONIFEROUS	LOWER PERMIAN	
	STEPHANIAN	
	WESTPHALIAN	D
		C
		B
		A
	NAMURIAN	
	VISEAN	
		PICTOU
		CUMBERLAND
		RIVERSDALE
		CANSO
		WINDSOR

Figure 1. Stratigraphic nomenclature for the Carboniferous strata, Cumberland Basin, Nova Scotia.

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

Rank 6 structures are small-scale cross stratification, current (parting) lineations, imbrication, flute casts, groove casts and associated erosional and tool marks.

Paleocurrent indicators were measured in the Cumberland and Pictou Groups for this study. In all, 1143 measurements were used in the compilation depicted in Figure 2. The vast majority of data (1095) represent measurements of individual troughs (rank 5 structures of Miall, 1974) taken primarily on well exposed coastal sections and river sections where three dimensional observations enhanced the reliability of the readings. An exception is data from the Springhill coalfield-Salt Springs area of the south-central basin. Here, larger scale structures were measured in open pit mine exposures (hollow-fills/channels; rank 4 and a macro-scale

hollow-fill/channel; rank 3 of Miall, 1974). Still higher rank data are provided by isopachs or margins of channel belts (rank 2) deduced from closely-spaced coreholes and mine workings. A negative aspect of these high rank structures is that they are bipolar with the direction of flow undetermined. Rank 6 structures were largely disregarded due to a lower degree of reliability (see discussions advanced by Miall, 1974).

For discussion purposes, sediment dispersal data are appraised for three geographic areas: (1) south-central Cumberland Basin, (2) western Cumberland Basin and (3) eastern Cumberland Basin.

SOUTH-CENTRAL CUMBERLAND BASIN

The data for this region come from the basal Cumberland Group fanglom-

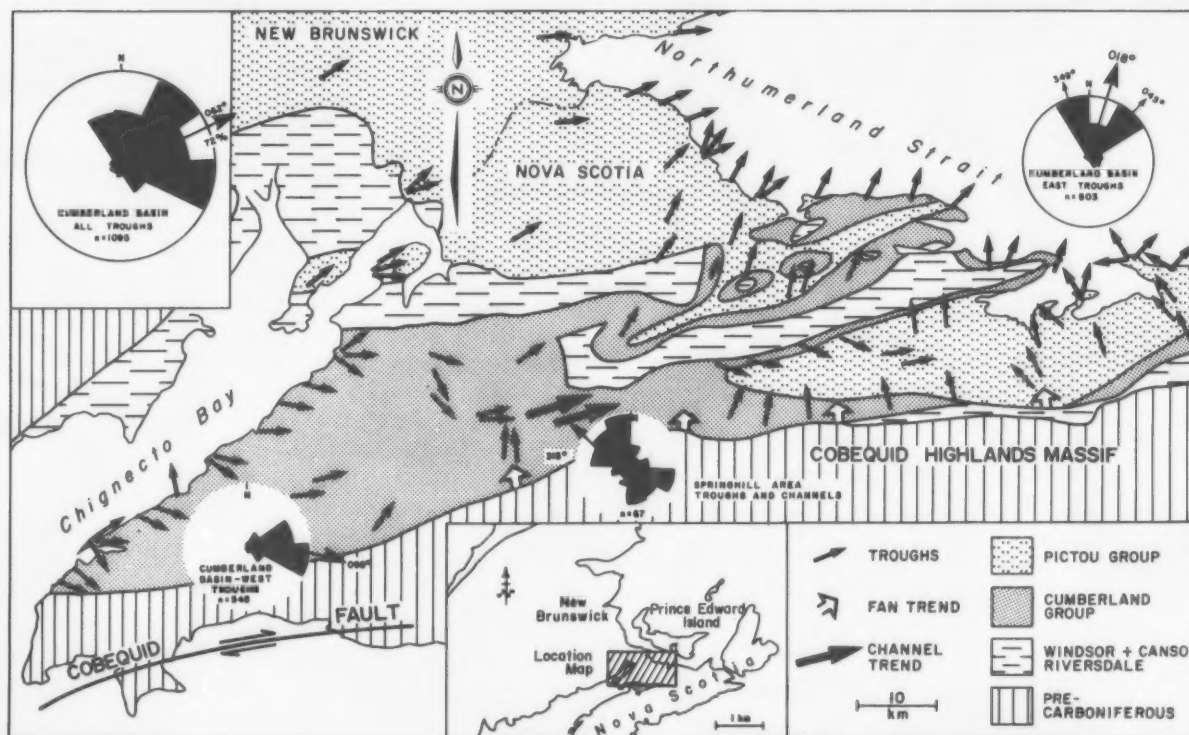


Figure 2. Sediment dispersal patterns of the Cumberland and Pictou Groups in the Cumberland Basin, northern Nova Scotia.

erates and penecontemporaneous coal-bearing fluvial strata of the Springhill coalfield and adjacent Salt Springs area. The approximately 600 m thick conglomerates and 1300 m thick coal measures of the Springhill coalfield are informally referred to as the Polly Brook and Springhill Mines Formations, respectively. The latter package of strata is entirely of late Westphalian B age (Dolby, 1987).

A degree of caution is required in interpreting paleocurrent data for the south-central region. A combination of rank 3 to 5 structures (troughs and hollow-fills) for the region reveals a strong northwesterly, bipolar trend. Channel belts and belt margins (rank 2 structures), however, trend northeasterly, indicating a longitudinal (subsequent) drainage pattern parallel to the basin margin with the Cobequid Highlands Massif (Fig. 2). The overall nonweighted paleocurrent vector (azimuth) which indicates a north-northwesterly (approximately 315°) orientation reflects marginal, transverse drainage patterns of the fanglomerates and ephemeral, distal fan deposits of the Polly Brook Formation. These latter deposits were coeval with the coal-forming peat mires of the Springhill Mines Formation (Calder, 1984). At Salt Springs, rank 4 scour-fills exhibit a vector mean of $101^\circ/281^\circ$, whereas the few troughs indicate a mean vector of 044° .

WESTERN CUMBERLAND BASIN

Paleocurrents in the Cumberland and Pictou Group strata of the western Cumberland Basin are measurements from three-dimensional trough cross strata, greater than 50 cm in thickness (rank 4), exposed as wave cut platforms on the Joggins to Spicers Cove shoreline and along river sections in the interior of the area (Fig. 2). The sediment dispersal trend of the 548 measurements is strongly unimodal with a vector mean of approximately 095°

(Fig. 2). This trend is consistent throughout the various stratigraphic units of the Cumberland and Pictou Groups in the area with only minor variations of the trend found in areas adjacent to diapirs or near the basin margins (Fig. 2). The trend confirms easterly dispersal patterns documented for several portions of the area by Duff and Walton (1973), Rust et al. (1984) and Salas (1986). The dispersal trends tend to be more southerly in the area north of the axis of the Athol Syncline and northerly on the southern limb, indicating that the axis of the basin of deposition may have been nearly coincident with the axis of the syncline.

EASTERN CUMBERLAND BASIN

The eastern Cumberland Basin paleocurrent data are from large-scale troughs of the Pictou and Cumberland Groups exposed along the Northumberland Strait shore and along the rivers in the study area (Fig. 2). This part of the basin has two trends present: (1) the southern Tatamagouche Syncline trend of 349° (Fig. 2) and (2) the northeastern Cumberland Basin trend of 045° (Fig. 2). The overall eastern trend of 018° reflects the presence of the Cobequid Highlands Massif, which contributed recharge of water and a variance in the gradient of the basin margin. The Tatamagouche area exhibits a few southeasterly measurements on the northern limb of the syncline. These are attributed to flow away from incipient evaporite diapirs during the time of Pictou Group sedimentation (Ryan, 1986). This observation is confirmed by the presence of flat-lying Pictou Group strata unconformably overlying overturned Windsor Group strata in the area. The northeastern Cumberland Basin trend conforms well to the trends in Prince Edward Island and southern New Brunswick, indicating that the influence of the Cobequid Highlands Massif did not extend beyond the Tatamagouche Syncline area.

CONCLUSIONS

The overall sediment dispersal trend of the Late Westphalian A to Permian Cumberland and Pictou Group strata in the Cumberland Basin is northeasterly to easterly, indicating that a major source area was located southwest to west of the basin throughout much of the depositional history of these strata. The trend of basin dispersal conforms with the larger Maritimes Basin trends predicted by Van de Poll (1973). Variations in the trends occur adjacent to highland areas such as the Cobequid or Caledonia Highlands Massifs. These variations are caused by the influence of the highland recharge and sediment load influx from massifs along the basin margins. The extent of influence of these features is limited and trends assume the more regional basin trends within a few kilometres from basin margins. Minor variations in the trends also occur in the northern Tatamagouche Syncline and Minudie Anticline areas where flow diverges from the regional pattern due to slope gradient changes resulting from syndepositional diapirism. The apparent contradiction in orientation of the northwest-trending rank 3 and 4 structures and the northeast-trending rank 2 structures at Springhill may be explained by localized reaches within a channel belt being oriented obliquely to tangentially to the overall trend of the same river (see Figure 1 of Miall, 1974).

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GEOLOGICAL SETTING OF NATIVE SULPHUR OCCURRENCES IN NOVA SCOTIA¹

D. C. Carter, R. C. Boehner and G. C. Adams

INTRODUCTION

Deposits of elemental (native) sulphur represent a large portion of world sulphur supply. The majority of these deposits originated as bioepigenetic replacements of anhydrite or gypsum. In Nova Scotia, sulphur occurrences have been noted within the Viséan Windsor Group, a cyclic sequence consisting of clastic sedimentary rocks, carbonate, sulphate and high order evaporites including salt and potash. Two occurrences of native sulphur have been documented from mainland Nova Scotia: (1) from the underground workings of the Canadian Salt Company mine at Pugwash in the Cumberland Basin (Carter, 1987) and (2) from exploration drilling near Hilden on the northeastern margin of the Shubenacadie Basin (Campbell, 1967). A third occurrence from an abandoned gypsum quarry near Dingwall, Victoria County, is a poorly documented surface occurrence which is no longer observable (Adams et al., 1987).

OCCURRENCE AND CHARACTERISTICS OF NATIVE SULPHUR DEPOSITS

Bioepigenetic native sulphur deposits occur in two distinct geological settings: (1) cap rock deposits overlying salt diapirs and (2) stratabound deposits within evaporite sequences. Examples of cap rock deposits occur in Texas coastal salt

domes of the Gulf Coast Basin (Seni and Kyle, 1986) and examples of stratabound deposits occur in the Mesopotamian Basin of northern Iraq (Barker et al., 1979).

Elemental sulphur deposits have a number of common characteristics. They are associated with dominantly marine evaporite sequences in sedimentary basins where structural controls (joints, faults, fractures, flexures) have supplied extensive plumbing to allow for the mixing and flushing of artesian meteoric water systems through hydrocarbon-bearing strata and the evaporites. This flushing encourages the proliferation of sulphate reducing bacteria, most probably *Desulfrovibrio desulfuricans*, which obtains energy through the oxidation of hydrocarbons to CO_2 . This oxidation reaction occurs through the breakdown of SO_4^{2-} ions, releasing CO_2 and H_2S as waste products (Ruckmick et al., 1979; Barker et al., 1979). Elemental sulphur is deposited where H_2S is oxidized by oxygen present as excess SO_4^{2-} and CO_2 in anaerobic systems or by free O_2 in aerobic environments. In the bacterial breakdown of anhydrite and gypsum, Ca^{+2} ions combine with CO_2 to form biogenic calcite. The origin of elemental sulphur deposits by metabolism of petroleum and anhydrite/gypsum by anaerobic bacteria is supported by ^{34}S and ^{13}C fractionation data (Barker et al., 1979; Kyle and Price, 1986).

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

PUGWASH OCCURRENCE

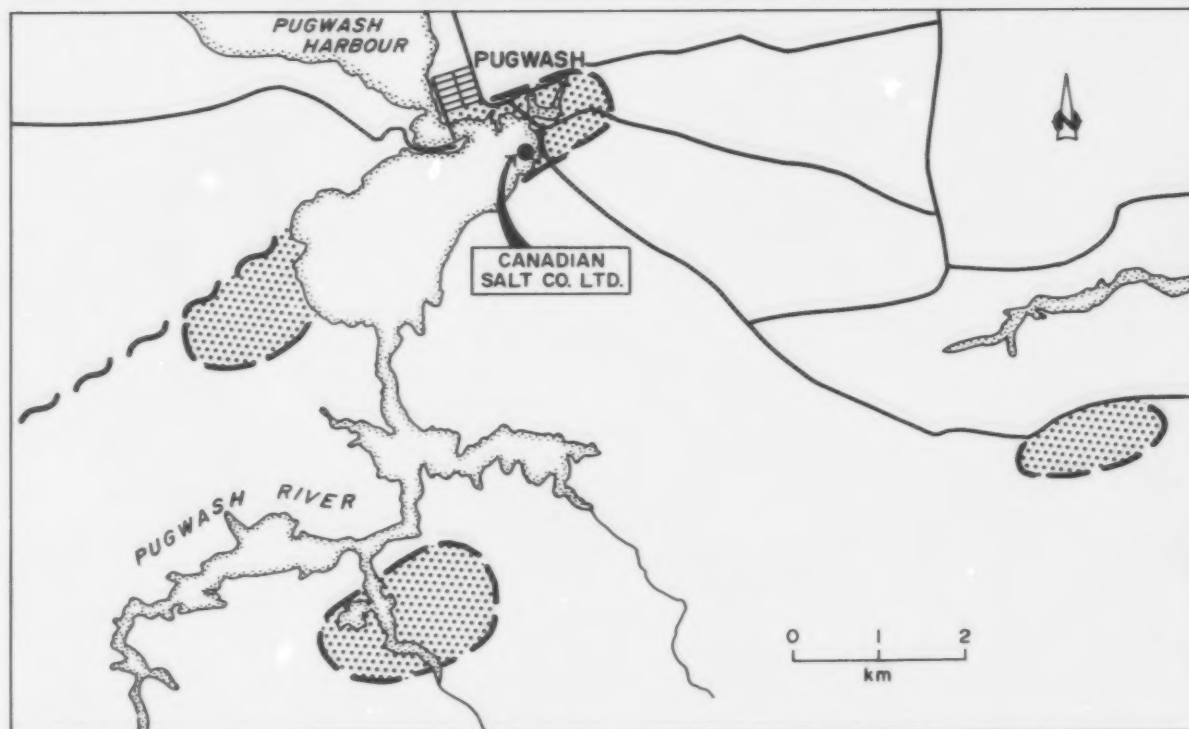
The Pugwash salt deposit is located in the Cumberland Basin, a large (3600 km²) structural subbasin of the Maritimes Basin, which contains a thick (over 7000 m) sequence of predominantly continental clastic rocks with one major marine incursion. The basin fill ranges in age from Devonian-Carboniferous to Early Permian and was deposited north of the Cobequid Highlands Massif and south of the Caledonia Highlands Massif following the Acadian Orogeny (Boehner et al., 1986). The Visean Windsor Group represents the only demonstrable marine incursion into the Maritimes Basin and is regionally widespread and up to 1000 m in thickness (Boehner, 1986; Boehner et al., 1986). Two east-west, en echelon, evaporite-cored anticlinal structures, the Claremont (Malagash) and Minudie Anticlines, transect the basin. The Canadian Salt Company mine, located at Pugwash (Fig. 1), marks the onshore eastern end of the Minudie Anticline and the Sifto Salt Division Amherst Plant brining operation is located at Nappan on the western end. The abandoned Malagash salt mine site is at the eastern end of the Claremont Anticline. The intervening Wallace Syncline contains several isolated, presumably diapiric evaporite structures (Boehner, 1986).

Recent work on the structure and stratigraphy of the Pugwash mine (Carter, 1986, 1987) indicates that the deposit is a piercement diapir and that a portion of the original deposit has been removed by surface erosion and/or groundwater interaction. Evidence for this includes: (1) the style of plastic deformation of both halite and anhydrite which suggests extensive flowage, (2) the folding, boundinage and passive rafting of anhydrite and halite units within a halite matrix, and (3) the attenuation and elimination of parts of the sequence which have resulted in a complex series of steeply dipping anhydrite units interstratified

with and isolated in a halite matrix. The geometry of the Pugwash River (Fig. 1) over the salt deposit represents dissolution and collapse of the uppermost portion of the diapir.

The anhydrite units exposed in the mine workings are lithologically distinctive and correlatable. One of the anhydrite units (informally termed the third anhydrite; Carter, 1986) contains minor amounts of elemental sulphur. This sulphur occurs with carbonate as a thin film surrounding and separating nodules of anhydrite. It is notable that this anhydrite unit occurs on the northern mining limit of the deposit, on the uppermost (630 foot) mining level and that it is in direct contact with hydrocarbon-bearing clastic rocks (Carter, 1986).

Similarities between the Pugwash salt deposit and the Gulf Coast Basin deposits in terms of general form and internal structure are striking. Although development drilling at the Pugwash deposit provided no documentation of cap rock and consequently no elemental sulphur showings have been reported, the presence of minor amounts of sulphur within the diapir suggest that conditions necessary to promote elemental sulphur deposition within the cap rock did exist at least on a limited scale. Figure 2 shows a generalized cross-section of cap rock sulphur deposits from the Gulf Coast area. The cap rock represents residual anhydrite accumulated by solution and removal of halite (Seni and Kyle, 1986). Subsequent conversion of all or part of the anhydrite to calcite by sulphate reducing, hydrocarbon consuming bacteria results in the deposition of elemental sulphur. This generalized cross-section stresses a number of factors necessary for the accumulation of biogenic sulphur deposits including recharge and pumping of artesian meteoric water, presence of petroleum-bearing strata, and the presence of permeable strata to



SIMPLIFIED GEOLOGY NEAR PUGWASH, N.S.

Figure 1. Map of the Pugwash area showing location of Canadian Salt Company mine and Windsor Group evaporite diapirs (stippled). Note relationship between enlarged Pugwash River and the Pugwash salt deposit.

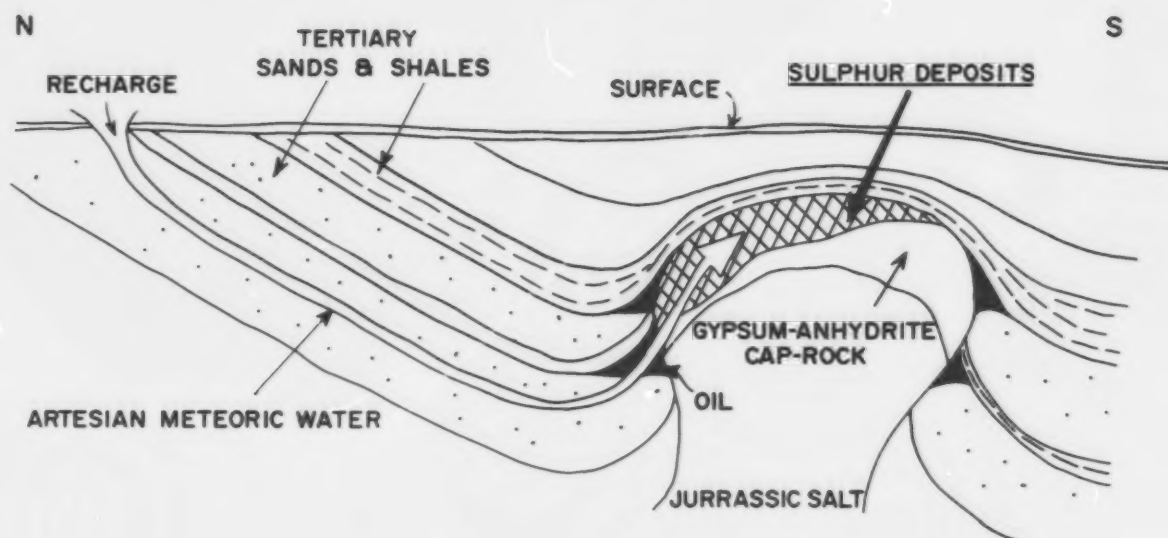
allow flushing and impermeable beds to seal volatile intermediate reactants.

The identification of suitable geological setting, structures and the presence of minor sulphur occurrences represents the first step in assessing the sulphur potential of isolated diapirs within the Cumberland Basin.

HILDEN OCCURRENCE

This native sulphur occurrence is located near the northeastern margin of the Shubenacadie Basin. Sulphur was first reported from the Hilden area in 1956 after veinlets of sulphur in gypsum and anhydrite were intersected in exploration drillholes (Campbell,

1967). In 1966 the Nova Scotia Department of Mines carried out further drilling which in turn prompted detailed exploration by New Senator/Peel Elder (Campbell, 1967). The geology of this area is complex and not well defined. The proximity of the area to the major faulting of the Cobequid - Chedabucto Fault and documented faults in the Shubenacadie Basin to the south (Giles and Boehner, 1982) suggests that extensive faulting is probable. Northeast-trending, high angle faults (Giles and Boehner, 1982), including the Rawdon and Roulston Corner Faults, merge northeasterly into the Brentwood-Graham Hill and Otter Brook Faults, which in turn merge into east-west faults parallel to the West



after Ruckmick et al (1979)

Figure 2. Generalized cross-section of Gulf Coast Basin salt dome cap rock development.

River, St. Mays Fault (Cobequid-Chedabucto Fault). The Hilden area is situated near this bend-merge area near the northern extremity of Windsor Group deposition. Figure 3 shows the simplified geology of the Hilden area with drillhole locations, depths and thicknesses of sulphur-bearing strata indicated.

Hydrocarbon shows, particularly bitumen, are locally abundant near the Windsor contact, especially 50 km west of Hilden near Walton. H_2S has been reported in drillholes in the Windsor Group evaporites. Bitumen and H_2S are associated with the sulphur at Hilden. The basal anhydrite of the Windsor Group appears to be the host for this native sulphur.

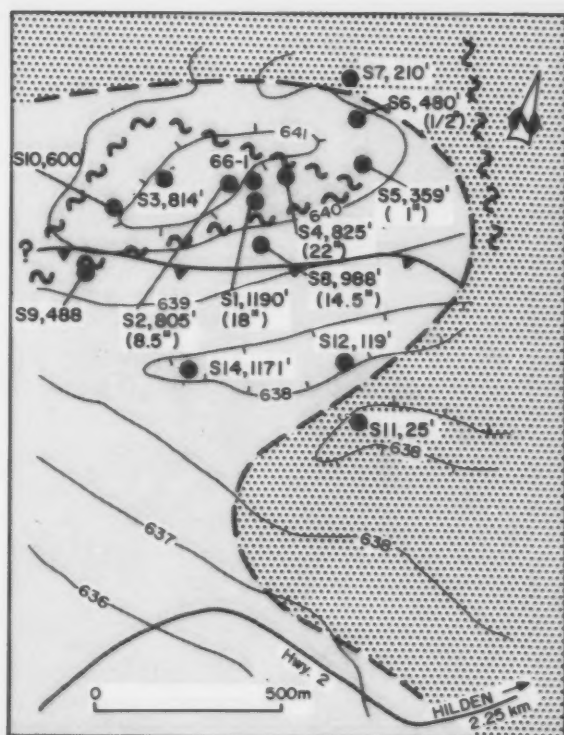
Horton Group siliciclastic rocks outcrop to the north of the disturbed sulphur-bearing gypsum/anhydrite outcrop area. Younger, middle-upper Windsor Group siliciclastics, evaporites and carbonates occur to the

south. The contact zone, as in other parts of the Shubenacadie Basin, is structural (faulted) and obscured by solution collapse. The extension of the basal anhydrite southward beneath the middle-upper Windsor Group has not been established nor has extension of the outcrop belt to the west been determined. Despite these unknowns the presence of elemental sulphur $\pm$ calcite $\pm$ hydrocarbon $\pm$ H_2S in this stratabound situation indicates that conditions favourable to the formation of sulphur did exist at this location, at least on a limited scale. A third elemental sulphur occurrence, from a stratigraphic position similar to that at Hilden, has been reported at Dingwall, Victoria County (Adams et al., 1987). This occurrence is poorly documented and no longer observable.

In terms of sulphur genesis there is no difference between cap rock and stratabound deposits, however, in stratabound deposits the anhydrite is present due to primary sedimentary

processes rather than as a dissolution residue. The formation of sulphur by anaerobic bacterial reduction of gypsum and anhydrite combined with the oxidation of hydrocarbons is characteristic of both.

A generalized cross-section of sulphur deposits in the Delaware Basin of western Texas is shown in Figure 4. The sulphur occurrence at Hilden may be analogous in terms of general geological setting. Interpretation of the west Texas deposits stresses the



SIMPLIFIED GEOLOGY AND GRAVITY
NEAR HILDEN, N.S.

Figure 3. Location map of area underlain by sulphur-bearing anhydrite of the Windsor Group (fine stipple) and underlying Horton Group (coarse stipple) near Hilden. Note the location of drill-holes; depths and thicknesses of sulphur-bearing section are given in inches.

unique combination of structural and stratigraphic controls that localize hydrocarbons, artesian circulation and the resultant sulphur deposit.

DISCUSSION

Bioepigenetic sulphur deposits are known to occur where structural controls such as faults, joints or flexures permit water, hydrocarbons and sulphur reducing bacteria to penetrate into an evaporite sequence. Bacterial oxidation of hydrocarbons, reduction and alteration of gypsum or anhydrite to biogenic calcite and the resultant deposition of elemental sulphur have been well documented (Davis and Kirkland, 1979; Feely and Kulp, 1957; Seni and Kyle, 1986).

Prerequisites for the formation of bioepigenetic sulphur deposits appear to be present within the Windsor Group of Nova Scotia: (1) a large sedimentary basin with a thick succession of sulphate-bearing, high order evaporite deposits; (2) known hydrocarbon occurrences from both within the Windsor Group and from the underlying Horton Group (McMahon et al., 1986; Short, 1986); (3) near surface presence of the evaporite sequence to permit interaction with meteoric artesian aquifers; and (4) structural complexity to produce the plumbing necessary to flush the system and to form the traps to contain the precursors of the sulphur forming reaction. The known sulphur occurrences at Pugwash and Hilden although minor, indicate that conditions necessary for the formation of elemental sulphur were met, and that potential exists within the Windsor Group evaporite sequence for the presence of significant, economic deposits of native sulphur.

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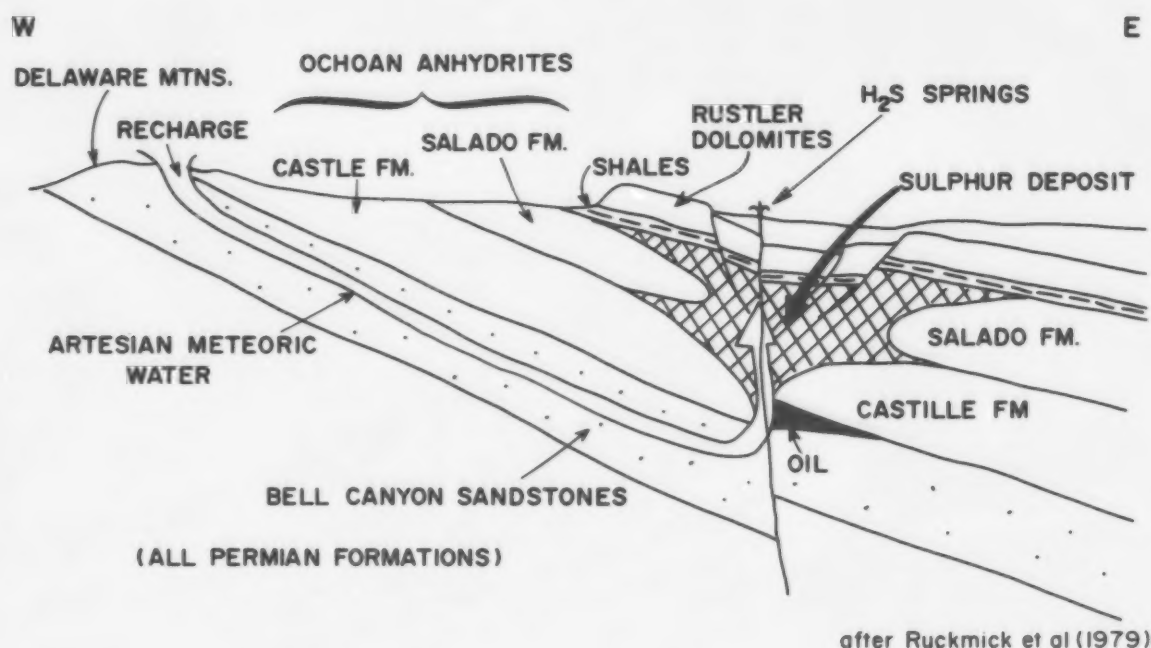


Figure 4. Generalized cross-section of a sulphur deposit from the Delaware Basin, west Texas.

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A MULTIDISCIPLINARY INTERPRETATION HIGHLIGHTING THE MINERAL POTENTIAL OF THE BEZANSON LAKE AREA, SOUTHWESTERN NOVA SCOTIA¹

P. W. Finck, M. C. Corey and R. M. Graves

INTRODUCTION

This paper results from research carried out as part of the South Mountain Batholith Project, a program funded by the Canada - Nova Scotia Mineral Development Agreement (CNSMDA). Recent regional mapping of bedrock (Corey, in press) and surficial deposits (Graves and Finck, in press) in the area of Bezançon Lake, Lunenburg County, has shed new light on the economic potential of the granitic rocks in that area (Fig. 1). The study area encompasses granitic rocks of the South Mountain Batholith (SMB) and Meguma Group metasedimentary rocks, both exhibiting the effects of intense and pervasive metasomatism and hydrothermal alteration (Corey, in press). Mineralization (exo- and endogranitic), found in boulders and bedrock, occurs in the form of polymetallic (As+Cu+Zn+Ag+Sn+W) quartz-muscovite greisen, quartz veins and quartz-fluorite breccia. A portion of the area is underlain by a large (2 x 3 km) airborne radiometric equivalent uranium/equivalent thorium (eU/eTh) anomaly. The anomaly coincides with numerous polymetallic greisen boulder showings and several polymetallic granophyre element till anomalies.

Recognition of distinct till units and clast dispersion within the units aids in further interpretation of the mineral potential. In areas of limited bedrock exposure the identification of

till clasts through field mapping and pebble counting can be used as reliable indicators of underlying bedrock geology.

PREVIOUS EXPLORATION

The coincidence of a large eU/eTh anomaly with previously discovered till geochemical anomalies at East Kemptville enabled Shell Canada Resources Ltd. geologists to recognize the economic significance of radiometrically specialized granites situated near SMB-Meguma Group contacts. Using this knowledge, Shell Canada Resources Ltd. geologists were attracted to a strong eU/eTh airborne radiometric anomaly in the Bezançon Lake area in 1979 (Fig. 1). Bedrock mapping, boulder prospecting, soil geochemistry, till surveys and geophysics were used in the exploration program. Prospecting located numerous quartz-greisen veins and boulders containing 0.2% - 0.4% Sn and up to 0.2% W (Sinclair et al., 1980). The extent of the bedrock Sn-W showings and the source of the mineralized boulders were not determined due to a general recession in the mineral exploration and mining industries by the end of 1981.

BEDROCK GEOLOGY

The study area contains both Meguma Group metasedimentary rocks and granitic rocks of the SMB. Five

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

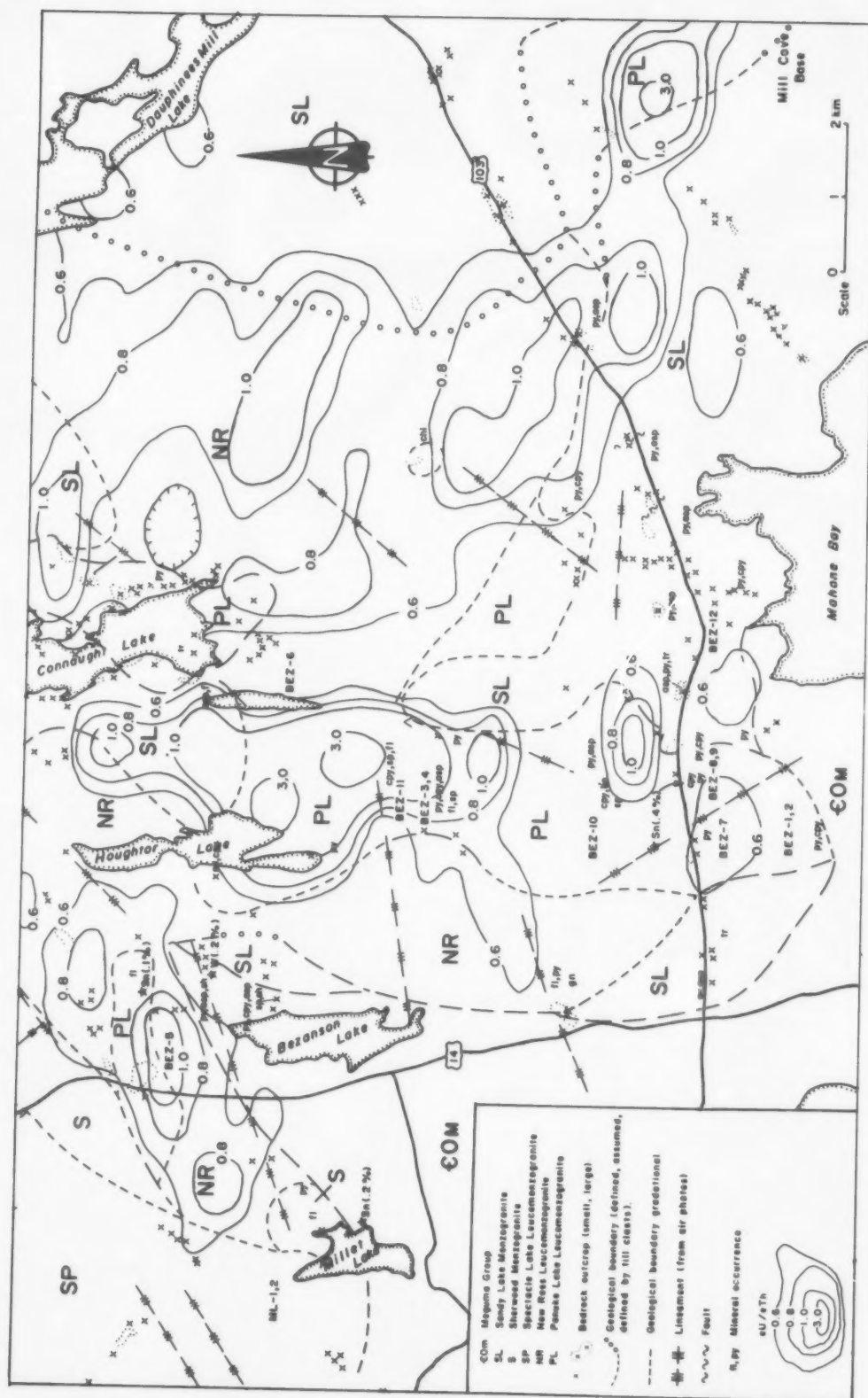


Figure 1. Bedrock geology and airborne gamma-ray spectrometric eu/eth map, Bezanson Lake area.

granitic units have been delineated in the Bezanson Lake area based on texture, mineralogy and alteration (Fig. 1; MacDonald et al., 1986, 1987; Corey, in press). Bedrock units are discussed in order from oldest to youngest.

MEGUMA GROUP

Occupying the southwest corner of the study area, this unit consists of slates (commonly pyritic) and sandstones belonging to the Halifax, Green Bay and Goldenville Formations (Fig. 1; O'Brien et al. 1985). Where observed, the contact of these rocks with the SMB is sharp and undeformed. Contact metamorphism has overprinted regional metamorphic assemblages and produced hard and massive spotted hornfels.

SANDY LAKE MONZOGRAHITE (SL)

This unit is predominantly medium- to coarse-grained megacrystic (10-20%) containing biotite (8-15%) and trace amounts of cordierite and muscovite. Adjacent to the Meguma Group contact this phase often exhibits a more equigranular texture. East and west of Connaught Lake large inliers of monzogranite occur which Corey (in press) assigns to this unit. Variable degrees of pervasive and fracture-related hydrothermal alteration (albitization, saussuritization, kaolinization and hematization) occur throughout this unit, and are particularly intense along Highway #103 immediately east of Highway #14. Significant fluorite and sulphide (As-Cu-Fe) mineralization is associated with the most intense alteration. Contact relationships indicate this unit to be the oldest granitic phase within the study area.

SHERWOOD MONZOGRAHITE (S)

This unit contains 8-10% biotite and significant amounts of muscovite (1-4%) and displays several textural

and gradational varieties. A fine- to medium-grained moderately equigranular phase of this unit is exposed at Millet Lake. It is intensely fractured and contains abundant fracture-controlled fluorite, minor quartz stockwork and quartz-sericite greisens. Northwest of Millet Lake this unit exhibits a fine- to coarse-grained seriate to slightly megacrystic ($\leq 5\%$) texture.

SPECTACLE LAKE LEUCOMONZO-GRANITE (SP)

Restricted to the northwest corner of the study area, this unit is characterized by a homogeneous, coarse-grained and extremely megacrystic texture (20-40% K-feldspar). It contains $\leq 6\%$ biotite, $\leq 3\%$ muscovite, $\leq 1\%$ cordierite and displays very little alteration except along a fault contact with the New Ross Leucomonzogranite (described below) where hematization is extensive.

NEW ROSS LEUCOMONZOGRANITE (NR)

This unit contains $\leq 6\%$ biotite and $\leq 5\%$ muscovite and has a predominant medium- to coarse-grained, moderately equigranular texture but locally may contain up to 15% K-feldspar megacrysts. This unit is characterized by a pervasive buff-orange colouration which is thought to be attributed to deuteric hematization (Corey, 1988).

PANUKE LAKE LEUCOMONZOGRANITE (PL)

This unit consists of two fine- to medium-grained, texturally distinct variations: (1) a homogeneous, light buff to greyish-pink equigranular phase and (2) a porphyritic phase. Both variations are similar to the NR in modal mineralogy. Panuke Lake Leucomonzogranite is most commonly confined to embayments or protuberances of the NR into older granite and metasediments. An exception to this occurs in the vicinity of Connaught Lake where a discreet PL body is sandwiched between two inliers of SL.

Contacts of these rocks with other units (SL) are sharp, however both gradational and intrusive contacts are common with the NR. Rocks of this unit commonly exhibit the effects of localized and intense metasomatic-hydrothermal alteration (albitization, desilicification, K-feldspathization, greisenization). As a result many of the mineral occurrences in this area are associated with these highly altered rocks (Fig. 1).

SURFICIAL GEOLOGY

Surficial deposits in the study area generally occur as three lithologically and/or genetically distinct types (Fig. 2a; Graves and Finck, in press): (1) alluvial and ice contact sands and gravels, (2) a ground moraine with a clast assemblage dominated by underlying bedrock lithologies and (3) ablation tills with a variable clast assemblage reflecting both underlying and up-ice bedrock lithologies.

(1) Alluvial and ice contact sediments form small but locally thick deposits of silt, sand, gravel and boulders along Middle River (Fig. 2a). These deposits are economically important and are actively being quarried for road and land fill. Geochemical anomalies and clast assemblages are especially difficult to interpret since the sediments are two or three times removed from their bedrock source and are therefore a less than desirable sampling medium for mineral exploration.

(2) The ground moraine is subdivided into three lithologically distinct facies in the study area: Granite, Greywacke and Slate Till B (Fig. 2a). Granite Till B (GTB) is the most widespread till in the study area, forming a flat to rolling ground

moraine. It is stony with a loose, yellowish-brown sandy matrix. In drumlin sections it is less than 2 m thick overlying Lawrencetown Till or Granite Till A (Graves and Finck, in press). As a ground moraine it varies in thicknesses from 1-6 m.

The average renewal distance for GTB is 100 m. The renewal distance, as defined by Peltoniemi (1985), is the distance (measured in a down-ice direction from the up-ice contact of a bedrock body) over which the proportion of a new rock type increases from 0% to 50% in the till. In a 2 m thick till exposure north of Dauphinees Mill Lake (Fig. 2a) greisenized granite bedrock was incorporated into GTB. At this location, the horizontal distance clasts have travelled from the bedrock-till interface to the till surface is less than 5 m. Transport of this altered bedrock is similar to transport distances envisioned for the most local of GTB. Clasts in the till can be used as a reliable indicator of underlying bedrock geology. On Figure 2a the dominant clast type in GTB is indicated by the letter symbol corresponding to the bedrock units described previously. Comparison of the bedrock geology map (Fig. 1) with the clast distribution (Fig. 2a) shows an excellent correlation. The dominant granitic clast type usually represents underlying bedrock, except over small intrusions or within the renewal distance of up-ice contacts.

Due to the limited dispersal of clasts in this till and the 2 km sample spacing of the survey, an exact dispersal direction could not be determined. However, field mapping indicates dispersion in a general southward direction (Graves and Finck, in press).

Greywacke and Slate Till B are lithologically distinct facies of GTB with similar textural and lithologic characteristics. Greywacke and Slate Till B have identical relationships

with underlying bedrock. These tills occur predominantly west of Middle River. The chemistry of these tills is not presented in this paper because the facies occur outside of the main study area. For a complete description of the tills refer to Graves and Finck (in press).

(3) Ablation till can be subdivided into 3 lithological facies with a spectrum of compositions reflecting both local and far travelled up-ice bedrock geology: Granite, Greywacke and Slate Till C. The proportion of clasts derived from local bedrock sources in these facies is highly variable. The till is defined on the basis of the clast type that represents local input from bedrock, regardless of the actual proportion of the clast in the till. For simplicity, ablation till was not subdivided into these 3 lithological facies on Figure 2a.

The ablation till forms a discontinuous hummocky moraine of till mounds that commonly coalesce to form sinuous ridges with low relief. It overlies and sometimes grades into GTB. Isolated mounds of ablation till occur across the entire map sheet. The variation in clast assemblages in the ablation tills limits their usefulness as a bedrock mapping tool. Similarly, geochemical anomalies in the ablation till are difficult to interpret due to glacial mixing of material from multiple bedrock sources, including very distant sources.

The average renewal distance in Granite Till C (GTC) is 3.5 km but varies from 280 m to 8.5 km. South of Millet Lake clasts of the Spectacle Lake Leucomonzogranite were observed in GTC 4 km south of the nearest exposed bedrock source area. Clasts identified as Millet Lake Monzogranite and Panuke Lake Leucomonzogranite are dispersed at least 2 km south of their bedrock source.

TILL GEOCHEMISTRY

SAMPLING AND ANALYTICAL PROCEDURE

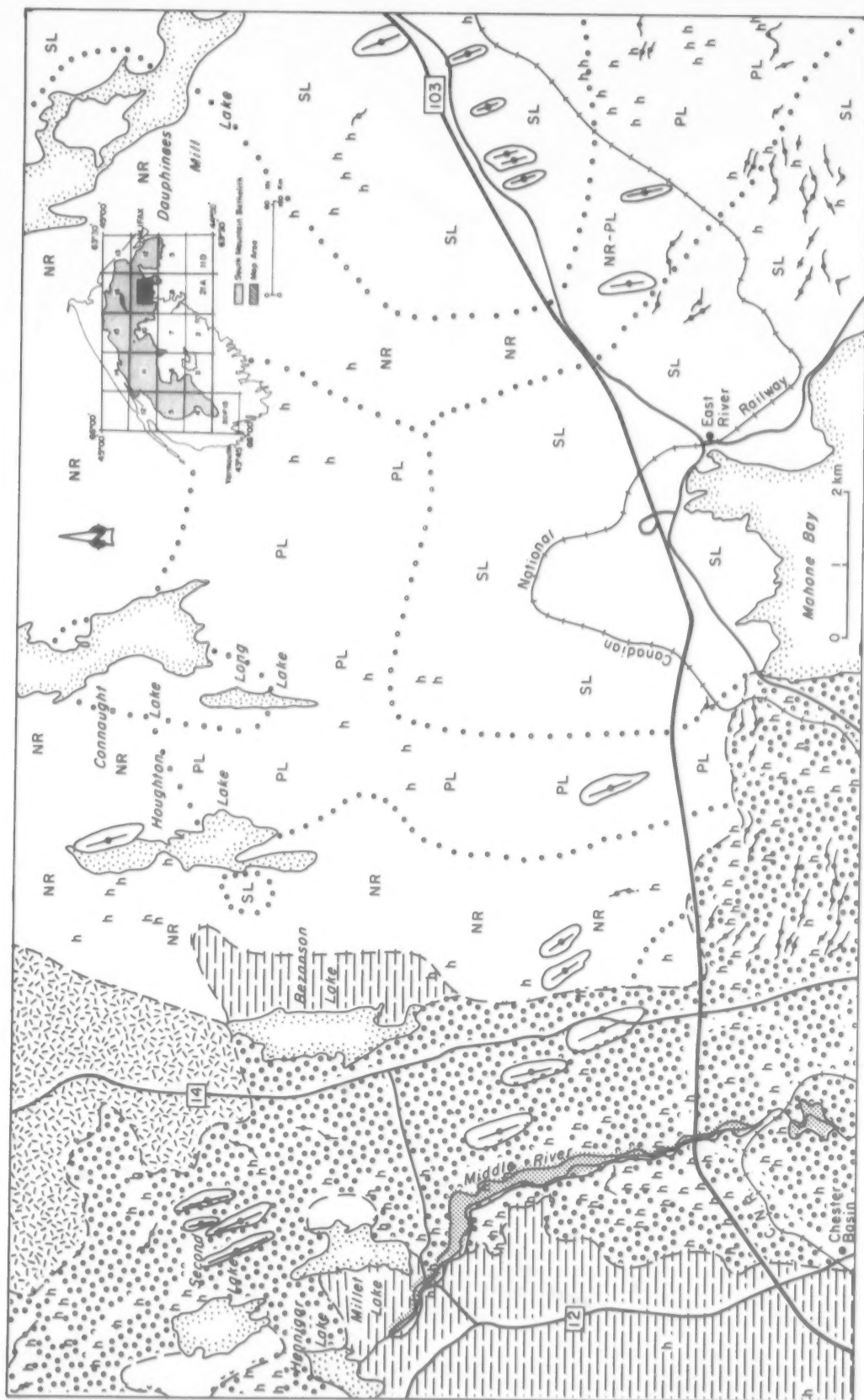
Glacial till was mapped and systematically sampled using available road cuts and by digging soil pits. Samples were collected from the C-horizon of till on a 2 km grid, except south of Houghton Lake and west of Mill Cove where additional samples were collected following results of original till geochemistry and boulder mapping.

Till matrix was submitted to the Minerals Engineering Centre of Nova Scotia for sample preparation and to commercial laboratories for analysis as outlined by Graves et al. (1987).

GEOCHEMICAL RESULTS

A multi-element value plot defines a strong clustering of anomalies south of Houghton Lake (Fig. 2b). Significant levels of W, Sn, As, Cu, Pb, and Zn are of particular interest (Table 1). Samples 5132 and 5133 have 77 ppm and 216 ppm W, respectively, in the -230 mesh fraction. The magnitude of these anomalies is similar to those reported for Sn in whole till samples collected in the vicinity of the East Kemptville Sn deposit (116 - 489 ppm, Wilson and Richardson, 1980). Scattered lake sediment W anomalies south of this area (Rogers et al., 1985) support the till geochemical results. There is no bedrock exposure south of Houghton Lake, however clasts in GTB suggest that bedrock is Panuke Lake Leucomonzogranite. Even though the matrix of a till is usually transported farther than the clasts, the extremely local nature of clasts south of Houghton Lake suggests that the multi-element anomalies likely reflect mineralization in the underlying leucomonzogranite bedrock.

A second clustering of anomalies (Sn, W, Pb, Zn, As) occurs near Mill Cove. Albitized and greisenized granite pebbles occur in the area of the till



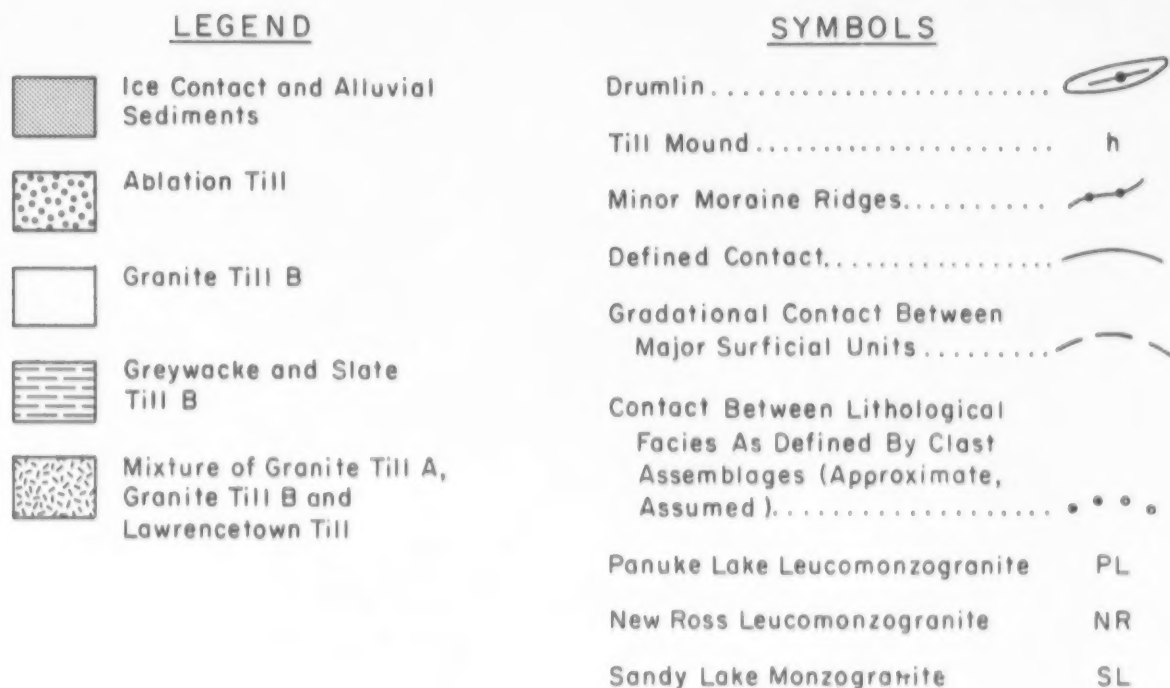


Figure 2. (a) Simplified glacial and till clast geology, Bezanson Lake area. (b) Multi-element anomaly value plot for Sn, W, Cu, Pb, Zn, As, U, Mo, Rb, Th and Sr, Bezanson Lake area. The anomaly value formula was modified after Rosenblum (1980). For elements that behave compatibly:

$$A_v = \sum_{i=1}^n (A_n/T_n)$$

where A_v is the anomaly value, A_n is the analytical value for the n^{th} element which is greater than or equal to its threshold value, T_n is the threshold value (95th percentile) for the n^{th} element and n is the number of elements in the series. For elements that behave incompatibly:

$$A_v = \sum_{i=1}^n (T_n/A_n)$$

where T_n is the threshold value (<5th percentile) for the n^{th} element, A_n is the analytical value for the n^{th} element which is less than or equal to its threshold value, and A_v and n are as above (over).

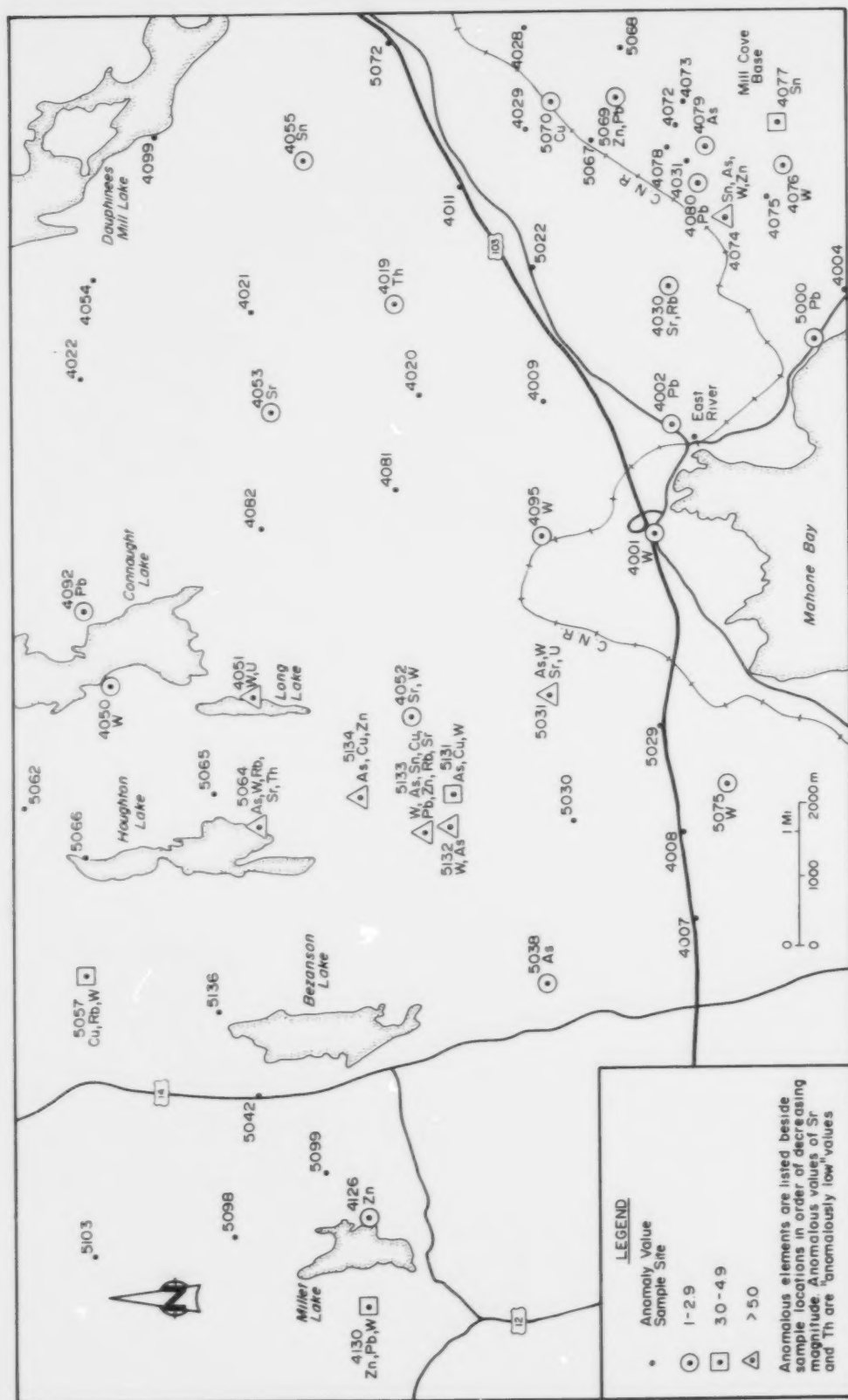


Table 1. Till geochemical results, Bezanson Lake area. Sample locations on Figure 2b.

SAMPLE	Sr*	Th*	Pb*	Zn*	Cu*	As*	Rb*	Mo*	W*	U*	Snwv
4001	63	19	30	70	20	33.0	190	2	20	6.1	0.259
4002	57	16	76	61	10	21.0	210	1	6	5.7	0.552
4004	54	16	29	45	4	6.4	210	1	4	5.5	0.141
4007	77	18	25	44	12	33.0	150	2	6	9.3	0.446
4008	77	19	21	63	13	17.0	150	2	5	5.0	0.061
4009	57	18	31	42	7	22.0	170	2	5	6.3	1.002
4011	66	27	22	75	22	33.0	250	1	6	10.0	0.011
4019	57	11	26	40	4	12.0	190	1	4	4.2	0.002
4020	63	18	20	45	8	11.0	180	1	4	6.6	0.028
4021	67	16	17	26	3	4.9	150	1	3	5.1	0.002
4022	52	20	20	44	1	19.0	190	1	4	7.7	0.003
4028	76	20	28	55	6	8.3	130	1	3	5.5	0.002
4029	72	16	23	41	7	11.0	140	1	4	4.8	0.002
4030	49	16	21	36	3	27.0	270	2	6	6.9	0.012
4031	53	15	21	30	2	21.0	220	1	7	6.7	0.090
4050	72	21	10	39	5	11.0	170	2	9	5.4	0.004
4051	59	27	32	86	9	14.0	230	1	38	14.0	0.053
4052	47	21	23	34	7	21.0	220	2	9	6.9	0.045
4053	44	12	34	50	0	15.0	170	1	5	5.9	0.156
4054	72	14	21	32	2	6.1	140	1	2	4.4	0.002
4055	67	17	26	38	11	10.0	140	2	7	5.0	1.268
4072	76	16	22	39	7	12.0	140	3	4	5.7	0.084
4073	77	17	25	38	5	12.0	130	2	5	4.8	0.014
4074	63	18	34	122	14	76.7	170	2	11	6.4	3.065
4075	72	16	34	49	7	16.0	110	1	4	4.2	0.388
4076	69	20	28	59	28	22.0	130	1	11	5.7	0.650
4077	78	20	32	70	10	18.0	120	1	3	5.6	4.526
4078	58	18	22	31	3	8.7	140	1	2	4.8	0.521
4079	60	20	14	53	9	49.0	210	1	5	5.8	0.142
4080	61	18	36	78	17	19.0	120	2	8	5.0	1.252
4081	50	16	17	26	3	10.0	180	2	5	5.8	0.738
4082	56	14	17	31	2	16.0	170	2	3	5.7	0.008
4092	64	17	36	85	17	16.0	200	2	5	6.8	0.109
4095	56	16	27	73	7	36.0	150	2	11	5.3	0.454
4099	72	18	34	38	6	7.3	120	2	2	4.6	0.101
4126	72	19	13	148	29	22.0	180	3	3	7.5	0.495
4129	58	26	3	37	5	8.1	170	2	2	7.8	0.276
4130	58	24	41	130	18	42.0	260	2	9	9.3	0.931
5000	56	16	43	48	18	8.0	180	2	4	6.3	0.093
5022	63	15	21	46	9	11.0	190	1	4	5.9	0.004
5029	53	14	19	37	1	45.0	190	2	7	12.0	0.116
5030	64	14	18	34	5	28.0	130	2	6	4.3	0.248
5031	43	24	23	63	14	118.0	260	3	14	14.0	0.070
5038	71	17	25	78	23	66.3	150	3	7	5.7	0.835
5042	74	18	15	37	8	10.0	130	1	4	4.6	0.196
5057	50	23	14	88	87	7.5	280	3	9	11.0	0.002
5062	70	15	19	44	0	6.4	150	1	3	4.8	0.072
5064	39	10	34	73	12	73.9	390	3	13	11.0	0.033
5065	64	21	25	54	0	9.6	155	2	5	6.1	0.024
5066	74	20	26	46	0	7.7	110	1	3	4.6	0.003
5067	69	18	26	67	14	26.0	160	1	4	6.0	0.628
5068	59	20	26	51	0	13.0	180	3	4	8.2	0.884
5069	53	19	40	128	0	7.5	180	2	4	4.4	0.045
5070	67	26	28	63	66	8.7	230	2	8	7.1	0.079
5072	79	15	23	41	4	6.3	140	2	2	4.3	0.143
5075	66	20	31	54	8	30.0	160	2	9	8.5	0.933
5076	66	19	26	42	10	37.5	150	3	9	8.0	0.338
5098	71	19	26	52	1	23.0	180	2	5	5.8	0.234
5099	72	25	27	37	4	12.0	160	1	5	6.3	0.307
5103	72	15	20	50	4	10.0	140	2	2	5.5	0.441
5131	56	50	22	62	44	78.9	220	1	11	0.0	0.059
5132	55	50	33	74	29	414.0	220	1	77	0.0	0.470
5133	47	50	58	110	61	336.0	280	2	216	0.0	3.416
5134	61	50	27	126	56	158.0	210	1	8	0.0	0.106
5136	64	50	17	29	8	8.3	130	1	5	0.0	0.063

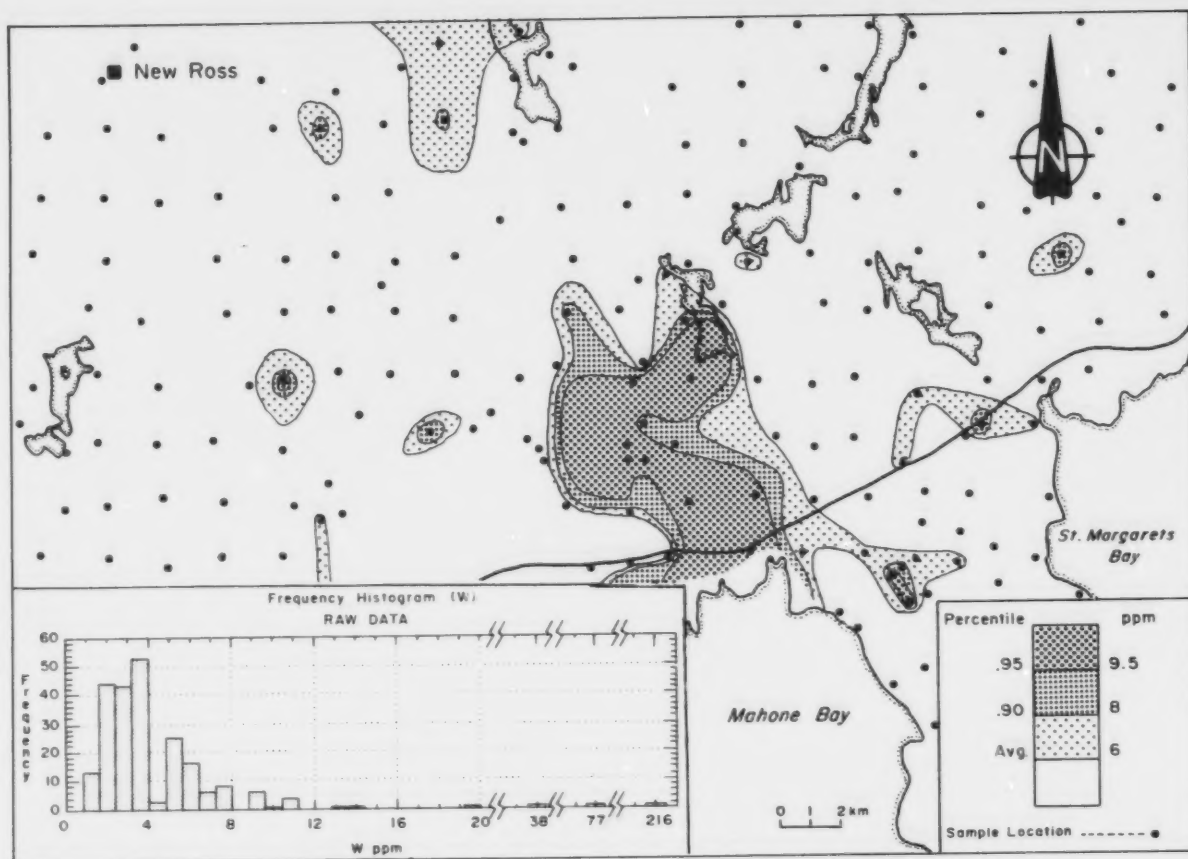


Figure 3. Contour plot of tungsten from the -230 mesh fraction of granite till, Map Sheet 21A/09 (Chester).

anomalies. Albitization and greisenization are common metasomatic-hydrothermal alterations associated with granite-related mineralization. The coincidence of clasts of these altered rocks with granophile element anomalies implies significant mineralization may underlie the till.

Less significant multi-element anomalies are scattered across the study area. They are generally of smaller magnitude, although spatial associations with bedrock and boulder mineralization are common (Figs. 1 and 2a).

Tungsten abundance in the -230 mesh fraction is contoured on Figure 3

and that from the heavy mineral concentrate (HMC) is contoured on Figure 4. Both plots show a similar distribution and highlight the areas south of Houghton Lake and near Mill Cove. The similarity between the -230 mesh and HMC chemistry indicates that costly HMCs are not necessary for W exploration within the study area. Contoured W values form a south to southeast belt corresponding to the distribution of Panuke Lake Leucomonzogranite clasts in the till, suggesting mineralization throughout the bedrock body. Alternatively, the belt of anomalies could be interpreted as a dispersion train. A complex scenario of south to southeast dispersion from multiple sources within

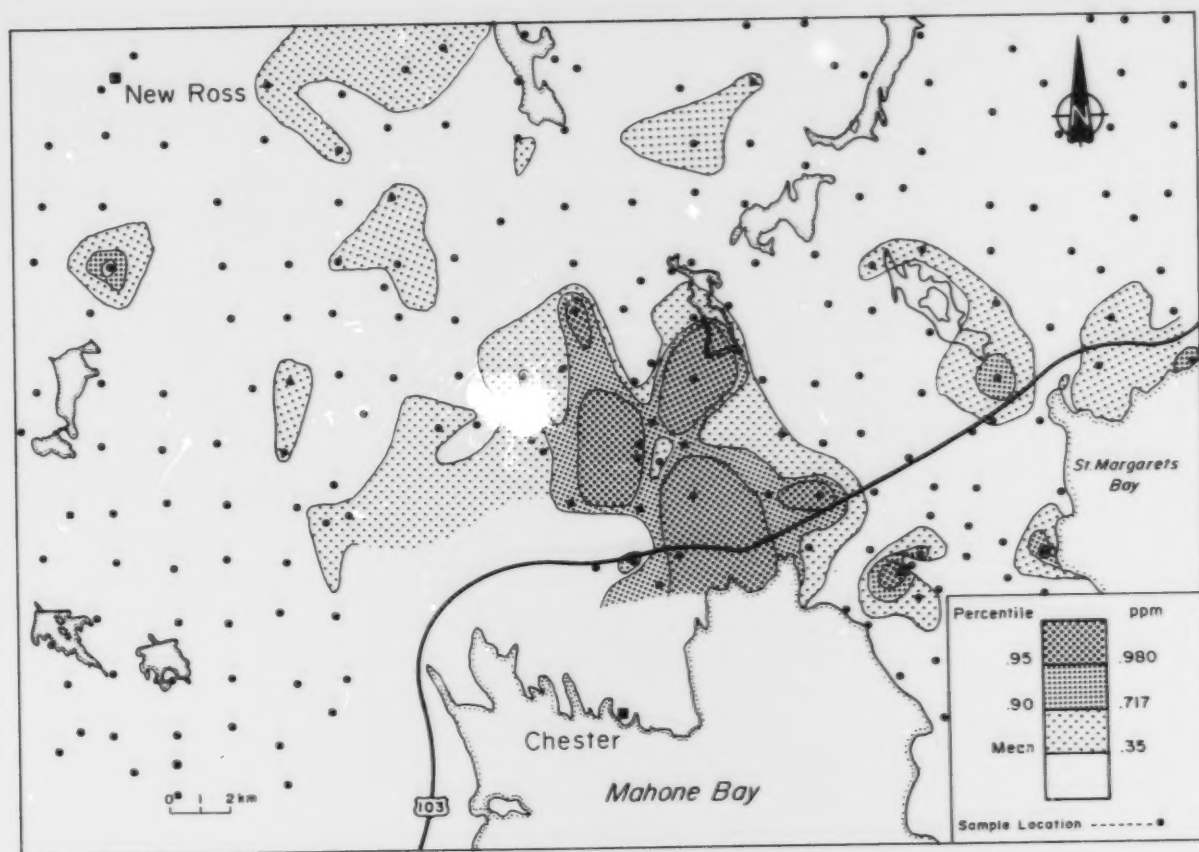


Figure 4. Contour plot of tungsten (weighted) from heavy mineral concentrates, Map Sheet 21A/09 (Chester). Raw heavy mineral analytical values for W were weighted as in Toverud (1982) using the formula: $A_{wv} = A_{rv} (W_1/W_2)$; where A_{wv} is the weighted analytical value (ppm), A_{rv} is the raw analytical value (ppm), W_1 is the weight of heavy minerals in the -50 + 230 fraction and W_2 is the total weight of the -50 + 230 mesh matrix used in the heavy mineral separation.

the bedrock body is preferred by the authors.

AIRBORNE GAMMA-RAY SPECTROMETRY

The eU/eTh data (Fig. 1) for this study is derived from 1 km-spaced airborne gamma-ray spectrometric surveys conducted by the Geological Survey of Canada (1978). Of particular note is the close correlation of PL rocks, mineral occurrences and till

geochemical anomalies with areas of elevated (i.e. > 1) eU/eTh ratios. The majority of occurrences fall within or in close (< 0.5 km) proximity to the high ratio anomalies. A similar correlation between mineralization and eU/eTh data can be observed at several greisen-hosted, polymetallic Sn±W deposits within the SMB (e.g. East Kemptville, Long Lake; Ford and O'Reilly, 1985; O'Reilly et al., in press). The occurrence of such a high ratio anomaly may be attributed to the presence of a highly differentiated granitoid and(or)

intense and pervasive metasomatism.

OCCURRENCES AND STYLES OF MINERALIZATION

As mentioned above, previous mineral exploration and recent bedrock and surficial mapping in the Bezanson Lake area have revealed numerous polymetallic ($\text{Sn} \pm \text{W} \pm \text{Cu} \pm \text{Pb} \pm \text{Zn}$) mineral occurrences (Figs. 1 and 2b). The occurrences are of several different types and display a wide variation in trace element concentrations (Table 2). Most of the mineral occurrences are found within the PL. The mineralization occurs in greisens, greisen bordered quartz veins and quartz stockworks, which have a predominant northwest-southeast orientation. A statistical study of linear features within the eastern half of the SMB has revealed that the majority of quartz veins ($N=381$) and aplite and pegmatite dykes ($N=640$) conform to a similar orientation (Horne et al., 1988) suggesting that their emplacement was structurally controlled.

Those mineral showings which are not hosted by the PL are either fracture controlled (e.g. ML-1,2; Table 2) or hosted by the Meguma Group and contact related. The presence of a fluorine-bearing fluid phase related to mineralization is evident by the presence of fluorite and the high levels of fluorine in the greisens.

Although the Bezanson Lake area contains many vein-type bedrock occurrences, the Sn-W content of the showings is highly variable. Based on data presented in this study, the area directly south of Houghton Lake has the best economic potential. The airborne eU/eTh anomaly (restricted to the PL unit) extends approximately 2 km along a general northerly trend. Radiometric patterns suggest that the southern and perhaps northern extensions of this anomaly have been truncated by northeast-trending structures (shears?). This structural

relationship is well exposed in a rock quarry 500 m east of Highway #14.

Some locations with relatively high Sn concentrations in float (BEZ 3,4,11; Table 2) have correspondingly low Sn concentrations in till from the same locality (Sample # 5133, 5134; Table 1). Tungsten in the boulder float samples (BEZ 3,4, 11; Table 2) is relatively low compared with W concentrations in the till matrix (Sample # 5133, 5134; Table 1). As mentioned previously, matrix and clasts (including boulders) in till may have different dispersion distances. The apparent difference suggests that clasts and matrix at these sites may represent different bedrock sources. As such, Sn and W mineralization in the study area may represent more than one mineralized bedrock source.

SUMMARY

(1) The area south of Houghton Lake has excellent potential for a greisen-hosted vein-type polymetallic ($\text{Sn} \pm \text{W} \pm \text{Cu} \pm \text{Zn}$) deposit. Tin, tungsten and sulphide mineralization may have discrete and separate bedrock sources. Fluorite is a common accessory mineral.

(2) Exploration should give top priority to an area of elevated airborne spectrometric response for eU/eTh underlain by Panuke Lake Leucomonzogranite south of Houghton Lake. Panuke Lake Leucomonzogranite bedrock near Mill Cove, associated with a eU/eTh anomaly, also has $\text{Sn} \pm \text{W} \pm \text{Pb} \pm \text{Zn}$ mineral potential.

(3) Mineralization is likely to occur in northwest trending greisen zones, greisen bordered quartz veins and quartz stockworks. A complex south-southeast dispersal of minerals derived from multiple bedrock sources is suggested by the large area of till anomalies coupled with very locally derived till.

(4) Little or no bedrock exposure

Table 2. Trace element analysis for bedrock and boulder samples from the Bezanson Lake area. Sample locations on Figure 1.

Sample no: type:	ML-1 A	ML-2 B	BEZ-1 C	BEZ-2 D	BEZ-3 E	BEZ-4 E	BEZ-5 B	BEZ-6 F	BEZ-7 A	BEZ-8 D	BEZ-9 B	BEZ-10 E	BEZ-11 E	BEZ-12 G
Ba	91.00	199.00	103.00	50.00	85.00	87.00	27.00	126.00	19.00	324.00	167.00	15.00	37.00	351.00
Rb	389.00	514.00	280.00	448.00	426.00	891.00	558.00	223.00	460.00	247.00	438.00	781.00	261.00	91.00
Sr	8.00	37.00	16.00	19.00	12.00	8.00	4.00	35.00	9.00	56.00	6.00	4.00	26.00	11.00
U	5.10	2.00	19.00	4.50	9.00	6.10	23.70	11.00	20.70	7.60	4.10	23.80	6.10	1.00
Th	11.00	17.00	9.30	4.30	5.20	8.20	6.70	7.00	2.60	15.00	5.70	2.90	11.00	1.50
Li	580.00	618.00	48.00	92.00	340.00	852.00	582.00	10.00	146.00	90.00	54.00	134.00	103.00	45.00
B	65.00	35.00	37.00	53.00	23.00	21.00	16.00	ND	23.00	29.00	32.00	30.00	17.00	38.00
F	6400.00	7200.00	1330.00	1770.00	6000.00	8200.00	4448.00	250.00	1385.00	760.00	1845.00	2750.00	1820.00	350.00
Cu	ND	1.00	4.00	2.00	3325.00	569.00	5.00	4.00	2.00	5.00	3.00	3458.00	217.00	1420.00
Pb	6.00	11.00	ND	16.00	208.00	792.00	62.00	24.00	20.00	13.00	ND	65.00	26.00	83.00
Zn	33.00	34.00	14.00	18.00	1884.00	366.00	65.00	21.00	81.00	53.00	15.00	228.00	36.00	4177.00
As	11.00	73.00	85.30	34.00	1100.00	50.00	50.30	108.00	1.90	3.80	151.00	327.00	5450.00	9000.00
Ag	ND	ND	ND	ND	12.20	5.80	ND	ND	ND	ND	0.40	7.00	0.40	4.60
Mo	3.00	3.00	ND	1.00	37.00	ND	2.00	ND	ND	ND	ND	13.00	12.00	6.00
Sn	33.00	30.00	7.00	33.00	339.00	1394.00	121.00	20.00	26.00	16.00	11.00	154.00	35.00	26.00
W	10.00	20.00	9.00	12.00	294.00	28.00	1090.00	3.00	11.00	4.00	12.00	61.00	29.00	24.00

A - hematized and fractured host rock, abundant fl along fractures

B - fl+py bearing quartz vein/stockwork

C - silicified & brecciated black greisen, minor py, asp

D - light green sericite-rich greisen, minor fluorite

E - silicified greisen, fluorite & sulphide-bearing

F - albitized

G - sulphide-rich quartz breccia

exists south of Houghton Lake. The till is locally thick and trenching may not expose bedrock. Detailed till sampling, boulder mapping and geophysics is recommended to locate trenching or drill targets.

(5) Clasts in Granite Till B can be used to map underlying bedrock, however careful distinction must be made between Granite Till B and C.

(6) Multi-element till anomalies reflect local bedrock mineralization.

(7) Analysis of the -230 mesh fraction from Granite Till B is suitable for W and possible Sn exploration in this area; costly heavy mineral separations are unnecessary.

(8) Anomalies in Granite Till C are difficult to interpret due to potential multiple bedrock sources. Granite Till B is a better sampling medium in the study area.

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PROGRESS REPORT ON A SURFICIAL GEOLOGY MAP OF NOVA SCOTIA¹

Y. Brown and R. R. Stea

INTRODUCTION

A surficial geology map of Nova Scotia is being prepared as part of the Canada - Nova Scotia Mineral Development Agreement. This compilation map will incorporate all available information on the surficial geology of the Province. The provincial map is being compiled using data from the 1:100 000 scale surficial geology map series (Stea and Fowler, 1979; Stea and Fowler, 1981; Stea, 1982; Stea and Grant, 1982; Stea, 1983; Stea et al., 1986) (Fig. 1, map sheets 1-9) and other available maps and reports pertaining to surficial geology in the Province. Data for Cape Breton Island should soon be available from the Geological Survey of Canada. Recent work is used to update older maps and data are then transferred to a base map

(1:250 000) of Nova Scotia.

Drafting of symbols on the 1:250 000 base map is over 50% complete. Glacial features represented on the final map include drumlins, eskers, moraines, roche moutonnee, kettles, limit of submergence, till units and areas of outwash, ice contact stratified drift and exposed bedrock. The finished map will be published at a scale of 1:500 000.

NORTHERN MAINLAND NOVA SCOTIA

In addition to the surficial map of the Province, four 1:100 000 scale maps of the surficial geology of northern mainland Nova Scotia are in preparation (Fig. 1, map sheets 10-13). Field work has been completed and drafting has begun on map sheets 10 and 11. Airphoto interpretation and compilation of sheets 12 and 13 has begun. These four surficial geology maps will provide greater detail than the 1:500 000 provincial map and can be used in conjunction with till geochemistry maps of the same area (Turner and Stea, 1987a; 1987b; 1988a; 1988b).

GLACIAL LANDFORMS

Eskers and drumlins in Nova Scotia have been studied in conjunction with preparation of the surficial geology map of the Province. Compilations of both features on mainland Nova Scotia have yielded interesting results.

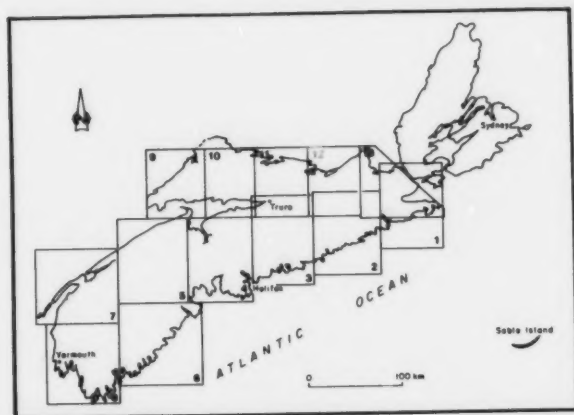


Figure 1. Index map of 1:100 000 surficial geology map sheets.

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

ESKERS

A compilation of eskers on mainland Nova Scotia was completed and their glaciological implications were determined (Brown and Stea, 1987). Trends and paleocurrent directions of the eskers support the directions of four ice flow phases postulated by Stea et al. (1987). Paleocurrent indicators from the eskers were compared to the proposed ice flow directions, thus enabling inference of the probable formation of eskers by the four ice flow phases (Fig. 2).

Southeastward ice flow of phase 1 may have influenced formation of some of the eskers in southern Nova Scotia that have southward paleocurrent indicators, although the southward flow of phase 2 likely played a more significant role. Eskers in Cumberland County and along the eastern shore of the Province have southward paleocurrent indicators and are also probably the result of southward ice flow during phase 2. In eastern Cumberland County, phase 3 northward ice flow from a central ice divide was likely responsible for the formation of an esker with northward paleocurrent indicators. West- and southwest-trending eskers in Hants, Colchester, Pictou, Antigonish and Guysborough Counties, the Annapolis Valley and southwestern Nova Scotia were probably formed by late phase 4 ice flow westward and southwestward from local ice caps on Prince Edward Island, the South Mountain and the Antigonish Highlands.

DRUMLINS

The numerous drumlins and drumlin fields on mainland Nova Scotia were compiled by the authors (Fig. 3) and the relationship between ice flow trends and drumlin formation was determined using striations, till pebble and boulder fabric, and provenance. A wide variety of drumlin shapes was noted, including long,

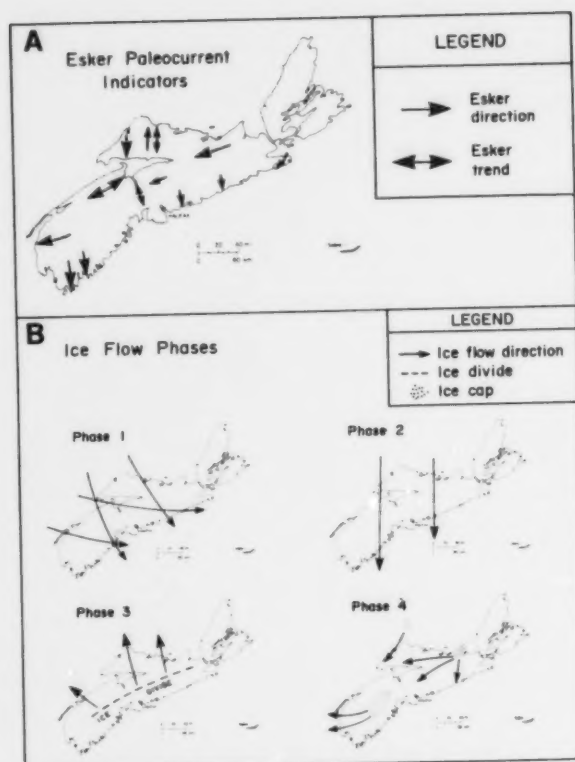


Figure 2. (A) General paleocurrent trends and directions indicated by eskers in mainland Nova Scotia. (B) Simplified diagram of ice flow phases in Nova Scotia (Stea et al., 1987).

attenuate, 'classic' and almost circular. An unusual 'compound' type of drumlin, which has axes parallel to two different ice movements, occurs in isolated areas (Fig. 4). The common internal layer cake structure of Nova Scotia drumlins generally comprises a core till formed by southeastward ice flow and a mantle till formed by a southward to southwestward ice flow.

A southeastward ice flow was the first and predominant drumlin-forming flow, as suggested by studies of core tills at the Terminal Beach and Meisners Reef drumlin exposures. At Terminal Beach, compound drumlin axes

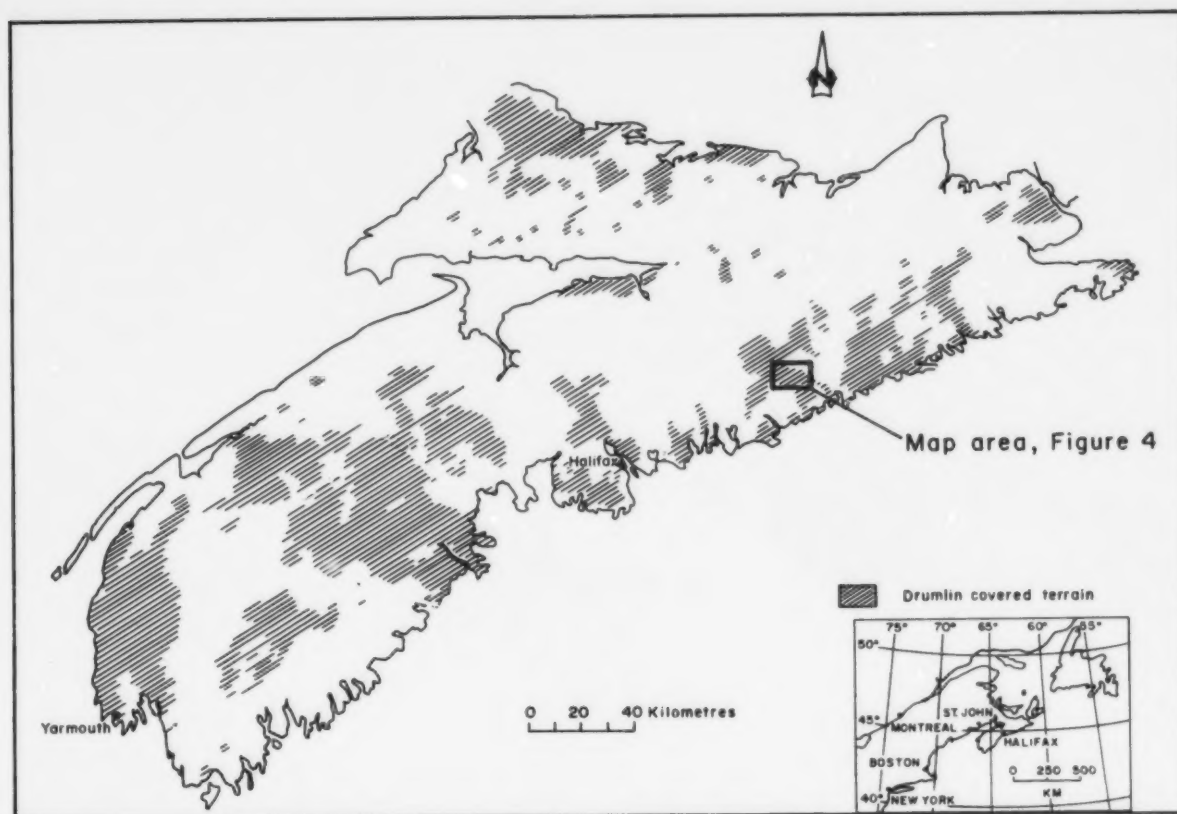


Figure 3. Drumlin covered terrain on mainland Nova Scotia.

and bedrock striations imply a later southward ice flow phase parallel to the inferred ice flow trend for the mantle tills.

The most significant drumlin-forming ice flow phase of the four ice flow phases of Stea et al. (1987) in Nova Scotia was the southeastward flow of phase 1. Ice flow phases 2-4 contributed to drumlin formation in the Province by reshaping earlier drumlins and forming new ones. Variations in till fabrics in the drumlins are largely a result of their multi-phase origin. Drumlin genesis in Nova Scotia involved both erosional and depositional processes. Drumlins formed during the early southeastward ice flow phase are largely depositional in origin. Those formed by subsequent southward flow were the result of both

depositional and erosional processes whereas drumlins resulting from later ice flow phases are generally erosional in origin.

SUMMARY

Compilation of all glacial features and surficial units on one map (1:500 000) will provide a clearer picture of the present day surficial geology of Nova Scotia and the glacial history of the Province. The 1:100 000 scale maps of northern mainland Nova Scotia will provide more detailed information on local surficial geology. The relationship between surficial geology and the responsible ice flows will be evident. Esker and drumlin studies have produced results which support the ice flow phases proposed by Stea et al. (1987).

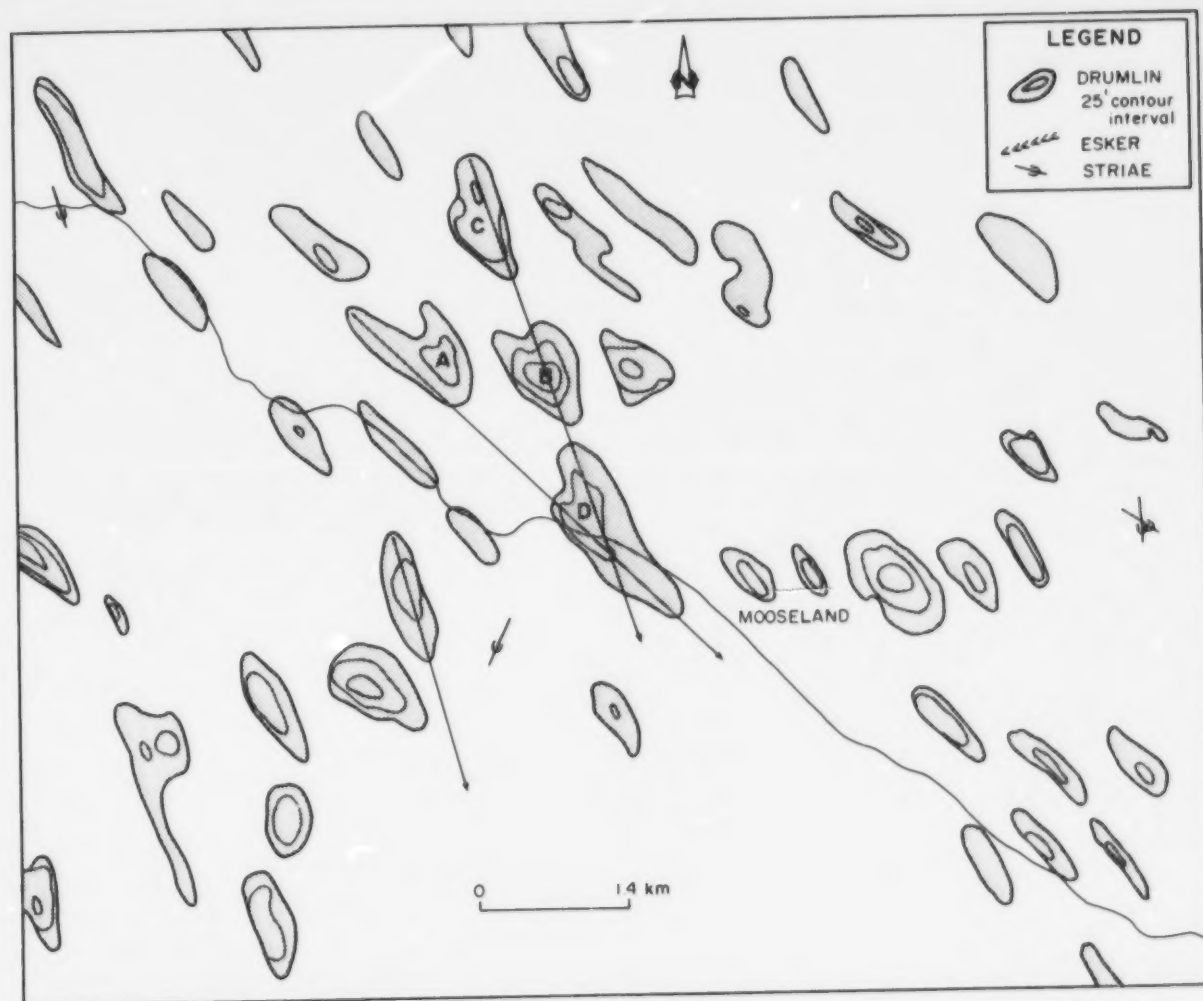


Figure 4. Drumlins near Mooseland. Note the compound drumlin forms A, B, C and D.

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Nova Scotia Department
of Mines and Energy,
Open File Map 87-005,
scale 1:100 000.

- 1987b: Till geochemistry of
northern mainland Nova
Scotia, Map 11-1987;
Nova Scotia Department
of Mines and Energy,
Open File Map 87-006,
scale 1:100 000.

- 1988a: Till geochemistry of
northern mainland Nova
Scotia, Map 12-1988;
Nova Scotia Department
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scale 1:100 000.

- 1988b: Till geochemistry of
northern mainland Nova
Scotia, Map 13-1988;
Nova Scotia Department
of Mines and Energy,
Open File Map 88-032,
scale 1:100 000.



SYMBOLIC REPRESENTATION OF TILL GEOCHEMICAL DATA FROM NORTHERN NOVA SCOTIA¹

R. G. Turner and R. R. Stea

INTRODUCTION

During the 1982-86 field seasons 950 till samples were collected from northern mainland Nova Scotia, between Parrsboro and Canso, at an average density of 1 sample per 13 km². These samples were analyzed for a suite of elements from the clay fraction (< 0.002 mm) and from the heavy mineral separates of the fine sand fraction (0.06-0.3 mm). The till geochemical data are currently being compiled on 1:100 000 scale open file maps. Two of these maps (sheets 10 and 11) have been released (Turner and Stea, 1987a; 1987b) and the remaining 2 sheets (12 and 13) will follow (Fig. 1). The latter 2 sheets will each have both a clay geochemistry map displaying Cd, Zn, Pb, Cu, Ag, U, Ni, Co, Fe, Mn, Ca, Mg, As and Mo data and a heavy mineral geochemistry map including W, Sn, Ba, Sr, La, B, In, Ga, Ge, Ag, Bi and Cr data. This paper describes the methodologies used in the preparation of geochemistry maps using star symbols as a means of condensing all available data onto one symbol and applications of these maps in mineral exploration.

MAP PREPARATION

Each map will include geology, mineral occurrences, anomalous and background till sample locations, an analyses list, summary statistics, an anomaly value key and descriptive notes.

Multi-element anomalies in the map areas were synthesized using anomaly values following the methods of Overstreet et al. (1978). Anomaly ratios were calculated by dividing the anomalous value of an element in a given sample by the threshold value for that element, as determined by the thresholds for the entire dataset for each map sheet (Overstreet et al., 1978). The anomaly value is the sum of the anomaly ratios for each element in a sample. The 95th percentile is used as a threshold and defines only the upper 5% of the data as anomalous. This is an arbitrary threshold; lower element levels may be significant. A multi-element map may compensate for significant element levels that are below threshold by revealing anomalies in associated elements related to mineralization.

Anomaly values are represented by star symbols on the map (Fig. 2), the corresponding sample number is italicized and the anomalous element values are darkened in the analyses list. The star symbol spike length corresponds to the strength of the anomaly and allows a comparison relative to other elements in the sample (Fig. 2). The analytical value (ppm or %) is listed in the analyses table on each map sheet.

The star symbol method was also used for heavy mineral analyses after weighting the data before the threshold

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

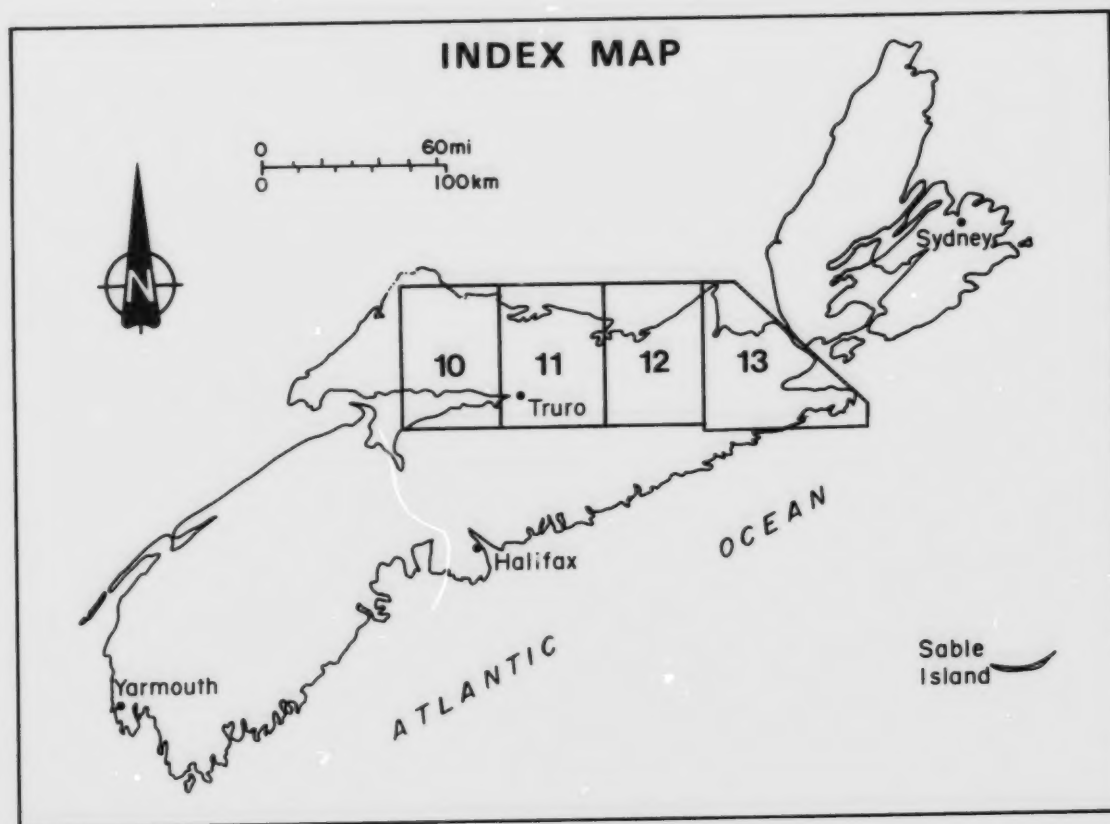


Figure 1. Index of map sheet locations.

levels for each element were calculated. The weighting procedure is described by Toverud (1982). The weighted value is equal to the weight of the heavy mineral separate divided by the weight of the fine sand fraction and multiplied by the analytical value (Toverud, 1982). The method corrects for the weight variations among heavy mineral concentrates in till samples and the unequal weights of the initial samples.

MAP APPLICATIONS

The star symbol is a useful tool for representing till geochemical data because: (1) it shows multi-element anomalies and element associations, (2) it shows the relative strength of each anomalous element in the sample and (3)

all the data can be plotted on one map (Fig 3). The 1:100 000 scale

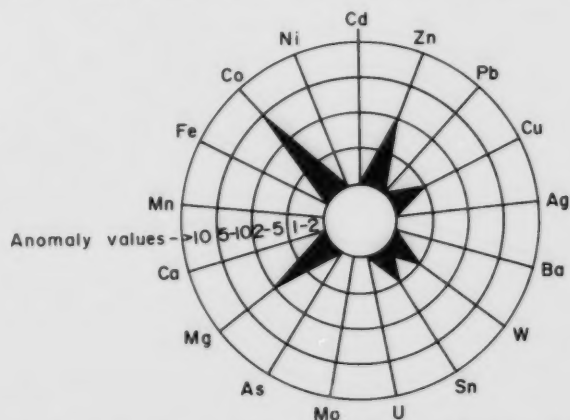
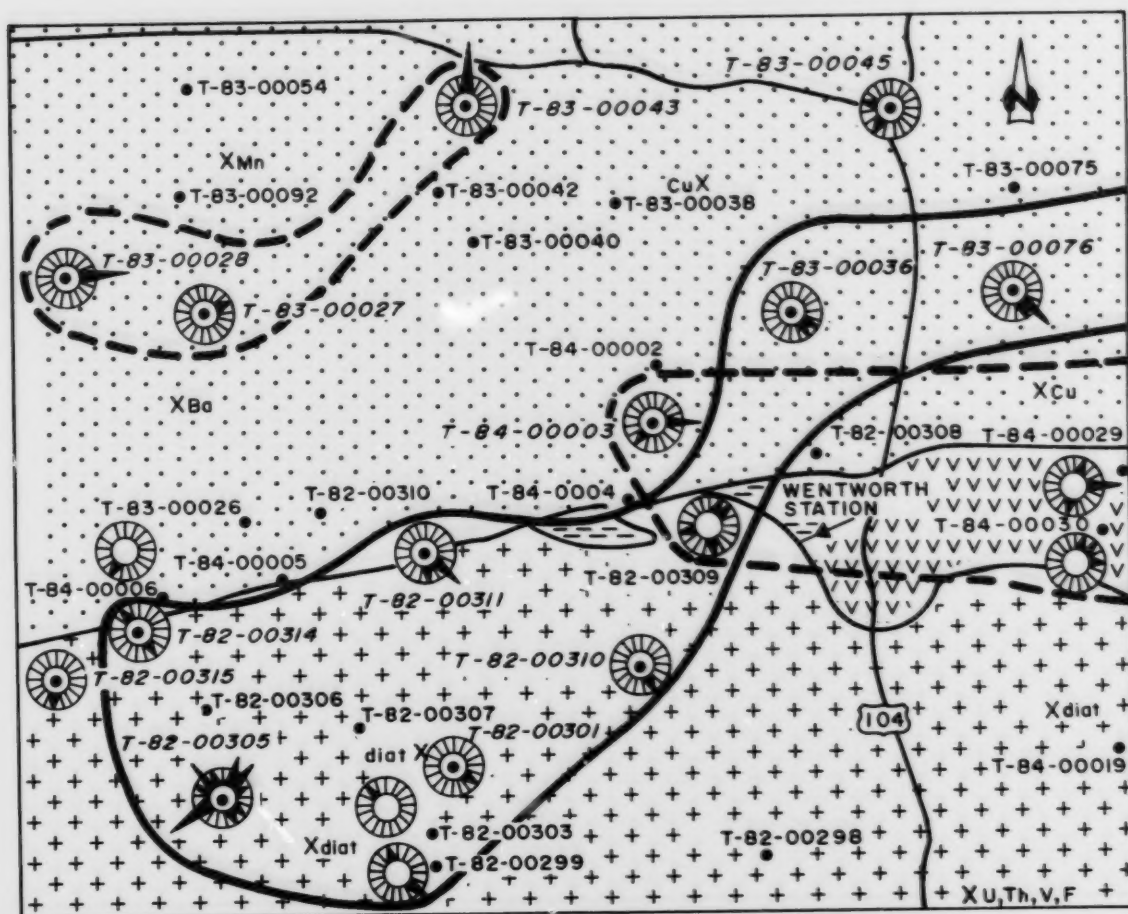


Figure 2. Key to anomaly values as depicted in the star symbol. This symbol shows the relative strength and position of anomalous elements.



GEOLOGY

GEOCHEMISTRY

Carboniferous

clastic sedimentary rocks

Devono-Carboniferous

granitoid rocks

Devonian

Byers Brook Formation
volcanic and clastic
sedimentary rocks

Silurian

clastic sedimentary and
volcanic rocks

X Cu mineral occurrences

• till sample location



anomalous till sample location

Sn-W association

Cu-Pb-Zn-Cd-Ag association



104 highway

0 2 4 km
0 1 2 3 mi

Figure 3. Portion of Open File Map 87-005 (Turner and Stea, 1987a) displaying the star symbol representation of data and anomaly associations.

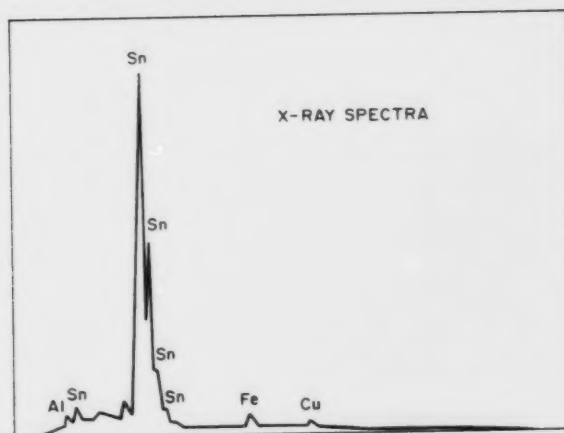
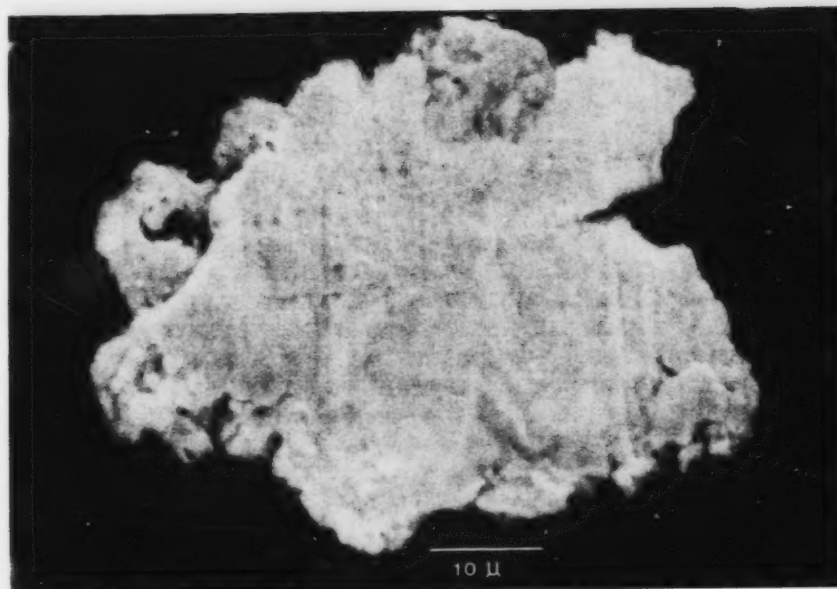


Plate 1. Electron micrograph and accompanying x-ray spectra for a weathered cassiterite grain identified in the heavy mineral concentrate from a till sample collected near Wentworth station.

surficial maps (in preparation) will allow overlays of the geochemical data with the surficial geology for comparison with till thickness, till type, ice flow direction and other surficial data.

The geochemical maps provide regional till geochemical information to the exploration geologist who is initiating a detailed survey. In areas with many anomalies, an "anomaly association map" can be constructed by simply joining groups of samples with

similar suites of anomalous elements (eg. Sn-W, Cu-Pb-Zn-Cd-Ag, Ni-Co, etc.). An example of this application occurs near Wentworth Station (Fig. 3) where a large area of Sn-W till anomalies is identified overlying Carboniferous granite. Tin-tungsten anomalies also occur overlying Carboniferous sedimentary rocks north of the Byers Brook Formation volcanics. Weathered cassiterite grains (Plate 1) were observed in heavy mineral concentrates from two till samples collected over these volcanic rocks

(Fig. 3). Chatterjee (1984) observed cassiterite in drill core from alkali basalt of the Byers Brook Formation and Rogers (personal communication) has identified cassiterite in stream sediment samples from this area.

The anomalies identified in till overlying Carboniferous sedimentary strata may relate to Sn-W minerals found in these beds, which consist of sediments derived from the Cobequid Highland Massif. Tin-tungsten anomalies identified over Carboniferous granites may result from glacial comminution of locally-derived granitic clasts containing elevated levels of Sn and W and(or) mineralization. These are only possible explanations for the Sn-W anomalies. The example serves to illustrate the use of star symbols and anomaly associations as a method of outlining areas with mineral potential for future exploration.

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1987b: Till geochemistry of northern mainland Nova Scotia map sheet 11; Nova Scotia Department of Mines and Energy, Open File Map 87-006, scale 1:100 000.



GOLD EXPLORATION IN THE MEGUMA ZONE: A PRELIMINARY UPDATE ON HEAVY MINERALS IN LAKE SEDIMENTS FOUND ON GRANITOID ROCKS FROM THE HALIFAX PENINSULA¹

P. J. Rogers

INTRODUCTION

Regional centre-lake bottom sediment geochemical surveys in Nova Scotia, as in the rest of Canada, have been widely used as a cost effective exploration tool. Lake sediments are perhaps unparalleled in their application to regional geochemical exploration as a means of rapidly covering and thereby assessing and identifying areas for follow-up study. Archived samples from the original 1977-1978 Meguma Zone lake sediment survey were re-analyzed for gold and other elements (Rogers et al., 1985). The new analytical data revealed numerous gold anomalies in the Meguma Zone (MZ). The Meguma Zone is dominated by two general rock types: metasedimentary, gold-bearing rocks of the Meguma Group and granitoid intrusives. Some of the gold anomalies are related to known gold deposits but others have a spatial relationship to granitoid rocks of the Halifax Peninsula (Fig. 1).

THE CATCHMENT BASIN MODEL

Previous research on gold in lake sediments (Coker et al., 1982) considered anomalies as discrete points and used contouring and other statistical methods to explain and link anomalous samples. In this paper lake sediment geochemical exploration is

approached in terms of modelling the catchment basin conditions. Each gyttja sample is considered to be representative of the composition of the lake catchment basin in which it is found. Surface weathering is recognized as the dominant control for most lake sediment systems in Nova Scotia. Lake sediments produced by surface weathering are thus directly related to the geological composition of the lake drainage catchment. Gyttja acts as an encoded imprint of the catchment basin's composition (Fig. 2).

Limnological studies of MZ lakes (Ogden, 1986) reveal that lake sediment drainage systems can be considered in terms of their potential for groundwater interaction. Ogden (1986) indicates the presence of an aquiclude, the tardelimmion, which is a zone of no ground water movement, in most Nova Scotia lake drainage systems. Significant groundwater interaction with a lake's water column occurs only in the perilimmion, a restricted outer zone (Fig. 2). Thus, the sediments sampled are the result of a mixture of mechanical weathering and hydromorphic processes. Groundwater does not have a significant input to lake sediment systems.

LAKES AS GEOCHEMICAL SINKS

Previous traditional lake sediment

¹ Funded by Geological Survey of Canada and Nova Scotia Department of Mines and Energy under Canada - Nova Scotia Mineral Development Agreement

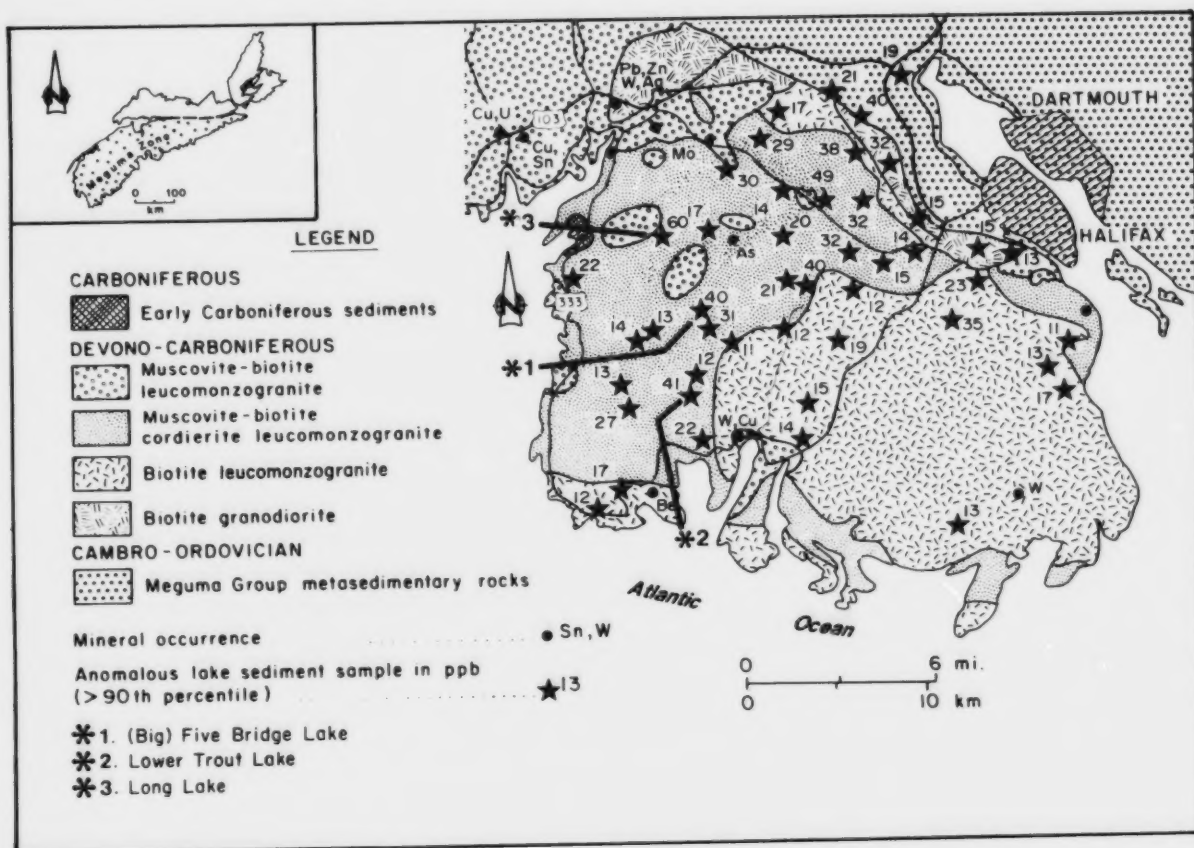


Figure 1. Gold anomalies in lake sediments and heavy mineral sample sites.

exploration models have assumed the pre-eminence of hydromorphic processes to generate anomaly-producing metal-bearing organic complexes (Timperley and Allan, 1974). Recent discoveries of significant mechanical weathering components in lake sediments near the East Kemptville tin deposit by Rogers and Garrett (1987) illustrate the role that lake catchment basins may play in capturing anomaly-producing heavy minerals in gyttja layers (Fig. 2). Therefore, lake sediments have significant hydromorphic and mechanical weathering components. Lake catchment basins may capture anomaly-producing heavy minerals as they enter the lake in gyttja layers. The heavy minerals are probably reworked to some extent within the lake system (Fig. 3a). Most heavy mineral particles detected to date in Nova Scotia lakes are small (a

maximum of 240 μm in length) and angular. The angularity indicates relatively short transport distances from either a direct bedrock or till source (Rogers and Garrett, 1987).

Bulk samples (about 50 kg) of lake sediment were collected from lakes with gold anomalies (Rogers, 1987) and wet screened to remove the heavy minerals by tetrabromoethane separation from the -60+230 and -230 mesh size ranges (Rogers et al., 1987). The heavy minerals were identified by scanning electron microscopy (SEM) at the University of New Brunswick. The variety of mineral species detected is startling, with the presence of phases previously unreported from Nova Scotia (Rogers, in press). In Figure 3b, heavy minerals detected from lakes developed on the granitoid Halifax

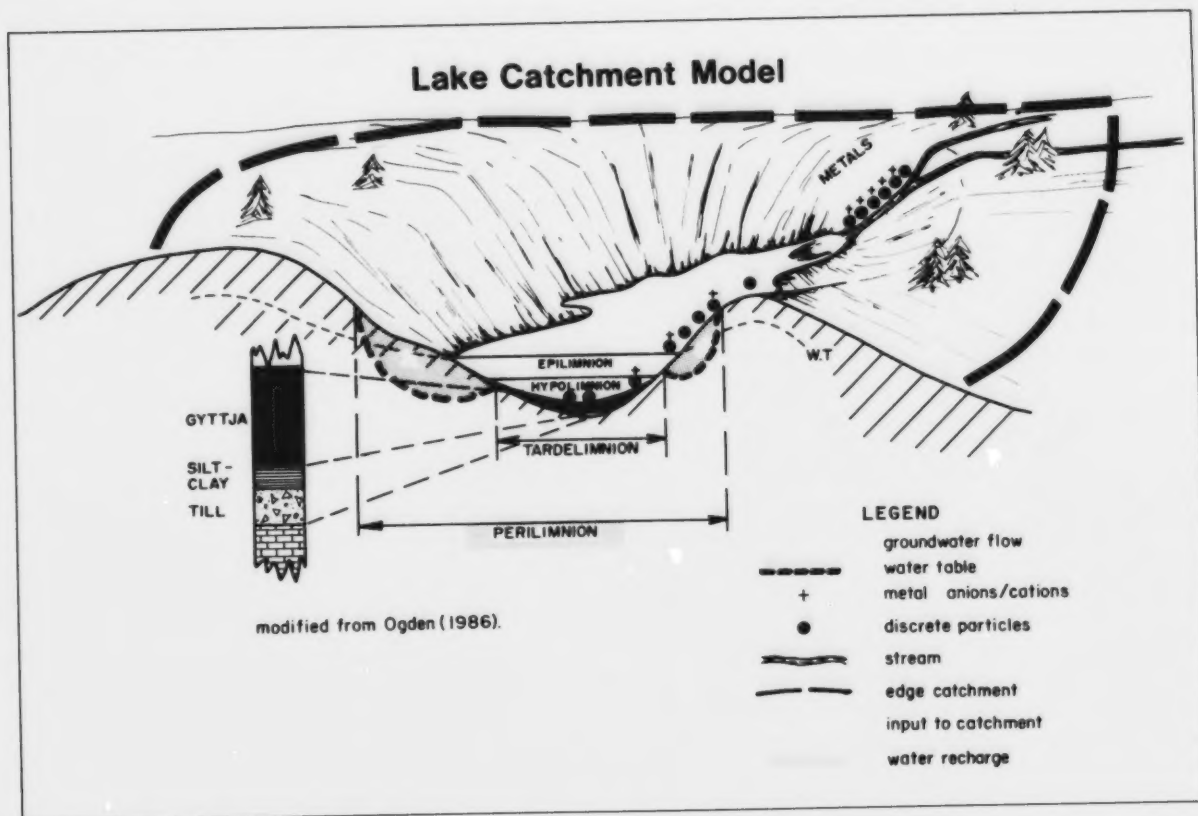


Figure 2. Catchment model for Meguma Zone lakes after Ogden 1986 with the tardelimmion and perilimnion. The perilimnion is the area of restricted groundwater interaction for most lakes in the Meguma Zone.

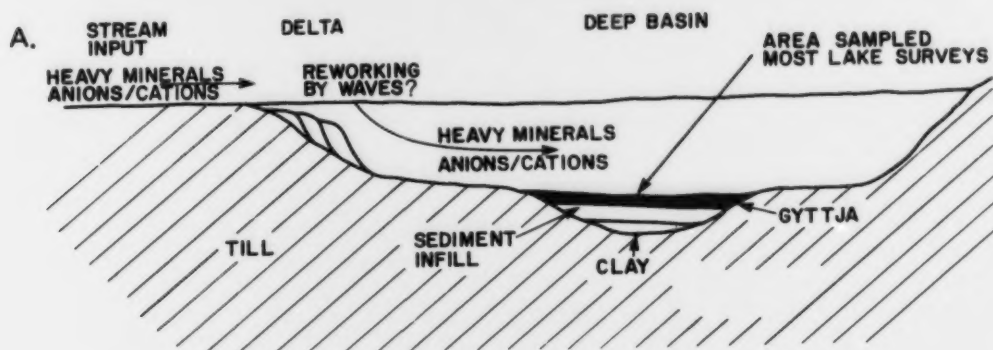
Peninsula are compared to those from Sealoom Lake, developed on Meguma Group rocks.

DISCUSSION

The SEM study confirms the first recorded presence of particulate gold in lake sediment from Nova Scotia (Fig. 4). Approximately $120\ \mu\text{m}$ by $40\ \mu\text{m}$ in size, the gold occurs in the very fine sand to silt size fraction. The study also documents the presence of unusual tin minerals, hoeschildite (SnO_2) and herzenbergite (SnS), found in both granitoid and Meguma Group lakes. These minerals were first identified in Bolivia (Dana, 1944) and this is the first reported occurrence in Nova Scotia. Hoeschildite has also been detected in a quartz vein from the

Forest Hill gold deposit (Watson, personal communication) and on inclusion planes in quartz samples from Meguma Group gold deposits (Smith, personal communication).

The variety of mineral species present in the lakes studied reflects similarities and differences between lakes on granitoid and Meguma Group rocks in the Meguma Zone (Rogers et al., 1984). The presence and preservation of sulphides such as pyrite, arsenopyrite, sphalerite and galena in the Meguma Group lakes contrast with the predominance of oxides such as zincite found in granitoid lakes. There appears to be no perceptible difference between both lake types for most other phases including cassiterite, scheelite and



HEAVY MINERAL PROVENANCE

B.

SPECIES	S. G.	LONG LAKE	FIVE BRIDGE	LOWER TROUT LAKE	SLOANE'S LAKE
SPHALERITE	3.9 to 4.1				
CHROMITE	4.1 to 4.9				
RUTILE	4.2				
BARITE	4.3 to 4.6				
ILMENITE	4.5 to 5.0				
HOSCHILDITE	4.5				
ZIRCON	4.7				
MOLYBDENITE	4.7 to 4.8				
PYRITE	4.9 to 5.1				
MONAZITE	4.9 to 5.3				
MAGNETITE	5.2				
ZINCITE	5.4 to 5.7				
FE SILICATE	5.5 to 6.0				
CUPRITE	5.8 to 6.2				
ARSENOPYRITE	5.9 to 6.1				
SCHEELITE	5.9 to 6.1				
CASSITERITE	6.8 to 7.1				
HERZENBERGITE	6.8 to 7.1				
GALENA	7.4 to 7.6				
NATIVE SILVER	10.1 to 11.1				
NATIVE GOLD	12.0 to 20.0				

MEGUMA METASEDIMENTS

GRANITOIDS

Figure 3. (a) Lake sediments capture heavy minerals in gyttja layers. (b) Table of heavy mineral species identified from 4 Nova Scotia lakes. Seloam Lake is near Liscomb, Guysborough County.

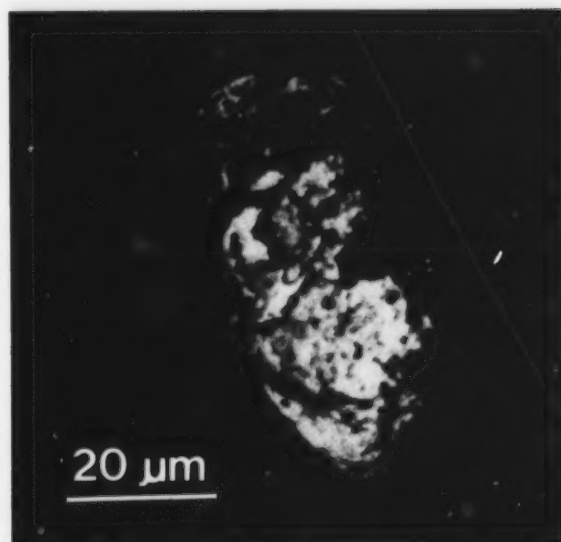


Figure 4. SEM photograph of particulate gold from a gyttja sample, Seloam Lake, Guysborough County, Nova Scotia.

monazite. The occurrence of granite-related minerals such as those in Seloam Lake probably indicates the nearby presence of granite or granite till in the lake catchment. The detection of chromite and magnetite in Five Bridge Lake may indicate contamination from a Meguma Group source or the presence of ultrabasic bodies in the area. The presence of barite particles is a mystery and might be significant for gold exploration. Finally, the tin minerals found are normally seen in the highly deformed intrusive rocks of the Bolivian tin producing area. Their occurrence as veins in Meguma Group rocks and as heavy minerals in lake sediments might indicate a closer relationship to Andean type conditions than previously considered for mineralization of the Meguma Zone.

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REGIONAL GEOCHEMICAL SURVEYS¹

R. F. Mills and P. A. Lombard

INTRODUCTION

A two year regional geochemical survey was initiated in May 1986 to sample stream sediments in the northern half of Nova Scotia (Mills et al., 1986) (Fig. 1). Approximately 5000 localities were sampled in the 1986 and

1987 field seasons. The main objective of the project is to provide heavy mineral stream sediment and stream water analyses. Streams were chosen as the sampling media because they are representative of large catchment basins and they are more numerous in the study area than are lakes. As part

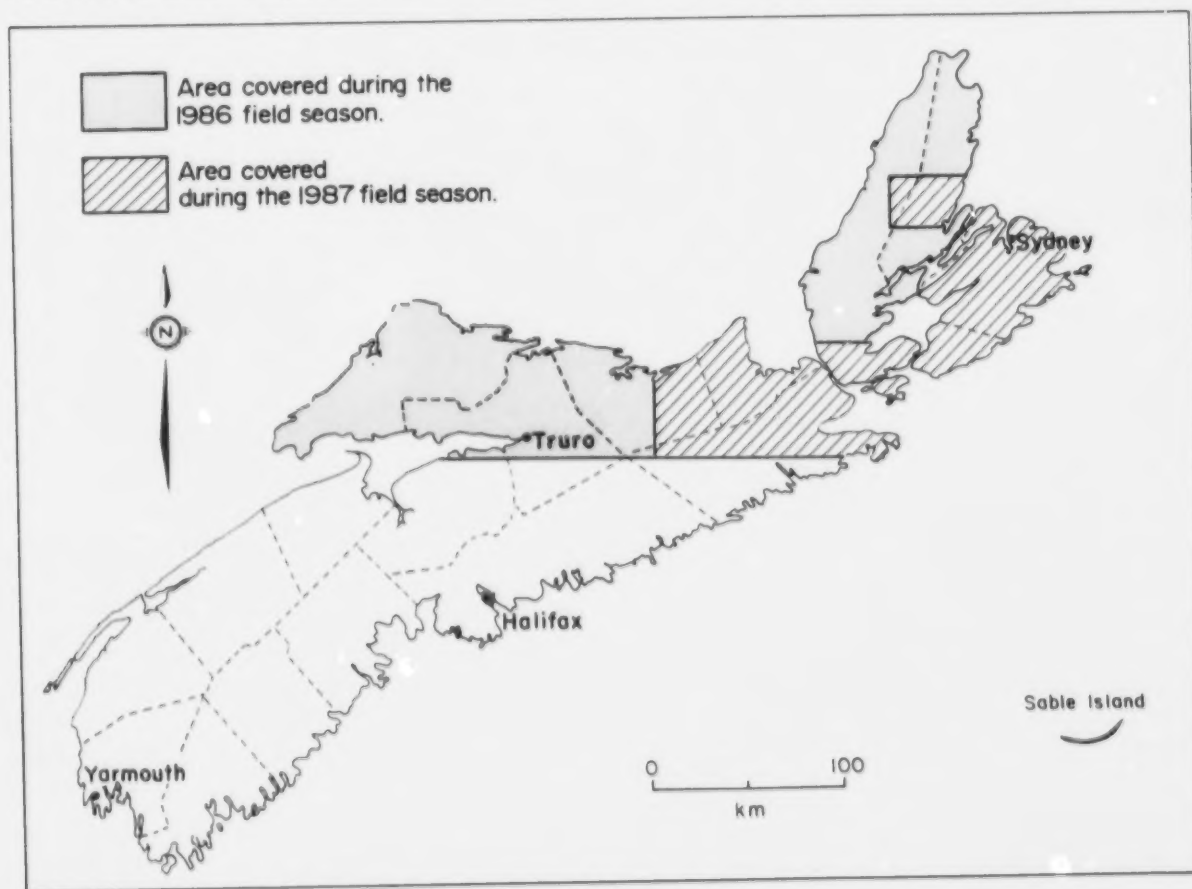


Figure 1. Field areas sampled during 1986 and 1987.

¹ Funded by Geological Survey of Canada under the Canada - Nova Scotia Mineral Development Agreement

of the Canada Nova Scotia - Mineral Development Agreement, a Geochemical Atlas will be produced. The atlas will consist of a database from Nova Scotia Department of Mines and Energy surveys. Derived from this database, the atlas will feature a series of geochemical maps compiled from various sample media in the Province. The atlas will employ new data analysis techniques, such as catchment basin analysis, as well as more traditional contoured maps produced on colour plotters.

ANALYSIS

Loss of fine gold grains is being minimized by saving all water while sieving in the field. Different size fractions are being analyzed. The -230 size fraction will be analyzed for a suite of precious and base metals as well as for their granophile, siderophile and chalcophile indicators. These analyses will be compared to results from the -16 +230 heavy mineral fraction from each sample, which will be analyzed for a similar set of elements (Fig. 2). Stream waters will be analyzed for U by fluorimetry and F by specific ion electrode. Field crews using portable instruments determined conductivity and pH levels at each sample site. This gave data on the degree of acidification, and hence digestion ability of local groundwaters.

SAMPLING TECHNIQUE

Samples were obtained behind natural traps such as logs, large boulders or the inside bank of a meandering stream. These are optimum trapping sites for heavy minerals that have been pre-concentrated by the stream. The sediment is wet sieved on site to pass through a -18 nylon mesh screen. The sample is collected in a plastic pan along with all of the water used during sieving. The -18 mesh sample and water are placed in a 3 ml gauze polythene bag and any air is

removed. The field sampling procedure attempts to minimize the loss of fine gold by preventing any loss of the water used during sieving, which has been documented to carry away fine gold (Boyle, 1979). Once transferred to field camp the samples are placed on a table and are not disturbed for at least 48 hours to allow the fine gold to settle. Excess water is then siphoned out of the bags and samples are packed for transport to the preparation lab.

QUALITY CONTROL PROCEDURES

Geological Survey of Canada sample vials are grouped into analytical batches consisting of 20 consecutively numbered samples. In every batch there are 2 field duplicates to determine field site variation as well as analytical duplicates and a standard, which are all randomly chosen and inserted in each batch of 20 samples. The analytical duplicates are used to measure analytical precision and the standard to measure the accuracy of the laboratory.

SAMPLE PREPARATION PILOT STUDIES

Erratic results from neutron activation analysis for gold can result from methods of heavy mineral separation used during sample preparation. A residue of Br left in some samples from the 1986 field season after tetrabromoethane heavy mineral separation is suspected of producing erratic results in neutron activation analysis for many elements, including gold. High levels of Br, which is highly excitable by radiation, will form broad high peaks on an analysis spectrograph. This masks the response of other elements to neutron activation, thereby raising their detection limits and seriously affecting the analytical precision.

To correct the problem, pilot samples treated by tetrabromoethane were washed in an ultrasonic acetone

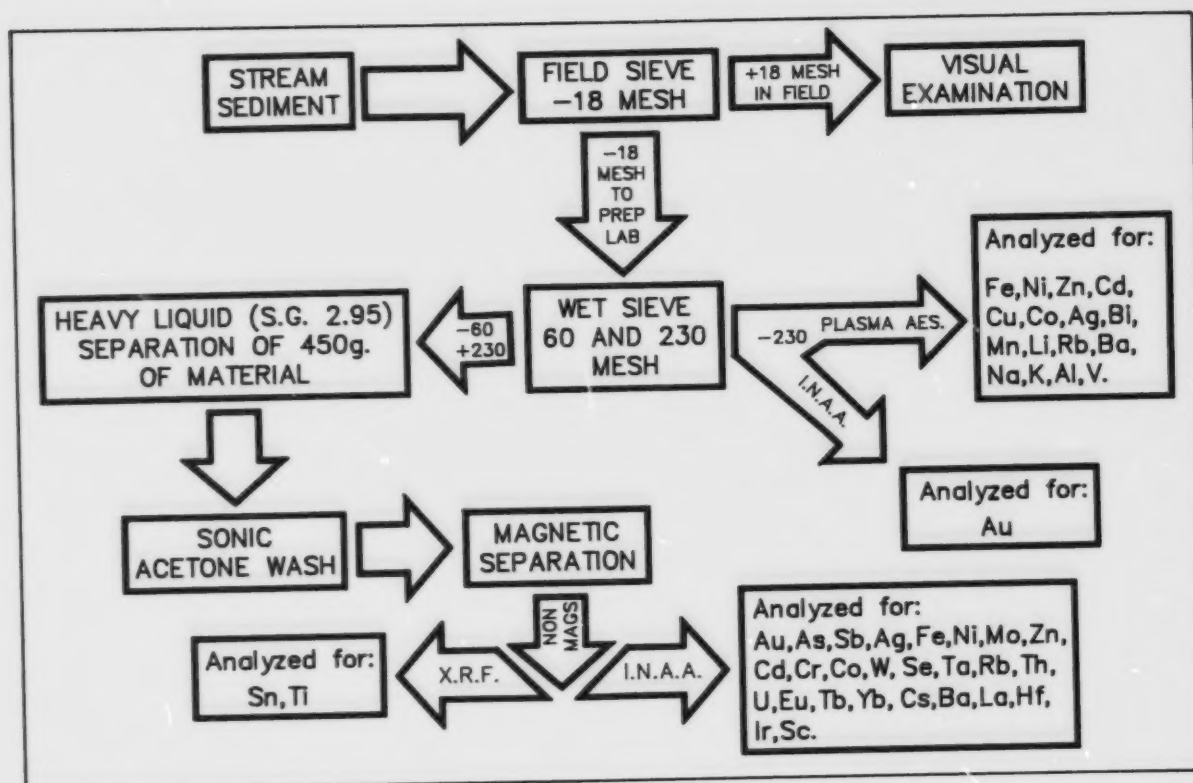


Figure 2. Flow chart of sample preparation and analysis.

bath. They were then split and sent to different labs for analysis after being irradiated by epithermal radiation. Samples not previously irradiated were cleaned by the sonic bath and presented no problems. Results indicated that the Br residue present on some samples cannot be removed once irradiation has taken place. The results of gold analyses that were inaccurate will be replaced by results from fire assay analysis.

The laboratory procedure for the 1987 field samples will include a pilot study with methyl iodide (iodomethane) as the separation medium. Once the analytical results are received from the methyl iodide separation they will be compared to the analytical results from the tetrabromoethane separation. It can then be determined which separation medium is best suited to

extracting heavy minerals from stream sediments in Nova Scotia.

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EDUCATION AND PUBLIC AWARENESS¹

H. V. Donohoe and M. E. Devanney

The Education and Public Awareness Program (EPAP) of the Mines and Minerals Branch and the Public Information Program (MDA-PIP) of the Canada-Nova Scotia Mineral Development Agreement (CNSMDA) share the objectives of disseminating information about the geology, mineral resources, exploration and mining activity in the Province. The interested public learns about these subjects and the government's involvement in them through the publication of informative literature, travelling displays, guided walks, talks and audio-visual materials.

Publications play an important supporting role in the many projects of the EPAP and MDA-PIP. To date, during the present CNSMDA, more than 30,000 publications have been distributed to teachers, students, tourists, government agencies, industry and the interested public. These booklets, newsletters and brochures cover a broad range of topics:

1. Regional geology: Point Pleasant Park, Halifax-Dartmouth, Peggys Cove, Victoria Park
2. Mineral resources: minerals and mining, mining history, gold, building stone, coal
3. Information on regulations: mineral rights, staking claims

4. Government projects/programs: Prospectives newsletters, Mineral Investment Stimulation Program

The Directory of Goods and Services for Exploration Companies provides a convenient reference to companies serving Nova Scotia's exploration industry.

In 1987, displays were exhibited in 20 locations throughout the Province and were viewed by more than 18,000 people. Many of these exhibits were in shopping malls where they would be exposed to a representative cross-section of the general public. A large number of those expressing interest were teachers on summer break looking for material with classroom potential. Two one-week-long display tours were the result of the collaborative efforts of the Department and Energy, Mines and Resources Canada (EMR).

The displays typically highlight the geology and mineral industry of Nova Scotia, as well as activities related to the CNSMDA. Displays would often include material of local interest, and specimens of both economic and interesting rocks and minerals. Very popular additions to the exhibit were the electronic mining quiz and the slide show entitled *The Mineral Industry of Nova Scotia*.

Other more technical displays are often co-ordinated by the Public

¹ Funded by Nova Scotia Department of Mines and Energy under the Canada - Nova Scotia Mineral Development Agreement

Information Group. These include the Annual Open House and Review of Activities and the Prospectors and Developers Association display. These displays are viewed by a much more specialized audience.

The Program is involved with education through participation in teachers' workshops, classroom presentations, instructional support at university field school and prospecting courses. In addition, the Program has been involved with the production of some supplementary educational material including the Mining Kit. This kit, which was produced in co-operation with the Nova Scotia Museum, includes samples of rocks and minerals of economic importance, slides, videos and an information package (brochures, posters, pictures and Teacher's Resource Guide). The videos in the kit illustrate two different commodities and mining methods used in the Province - Salt of the Earth examines underground mining at Pugwash and Real Tin describes the operation of the open pit tin mine near Yarmouth. The purpose of the Mining Kit is to stimulate interest and understanding of the Province's mining industry.

The EPAP has also offered consultation and advice in the production of a number of other 'rock videos'. The Mineral Wealth of Atlantic Canada and The Appalachian Story are part of a series of four videos being developed by the Atlantic Geoscience Society. The two videos that are not yet complete are The Recent Ice Age and Fossil Fuels of Atlantic Canada.

Walking tours are among the projects that have achieved the most success under the Program. To date, over 600 people have been guided on one of five walking tours that have been developed. The first of these walks - *A Walking Tour of Rocks, Minerals and Building Stones of Downtown Halifax* - was developed in 1985 to introduce the

general public to the rocks and minerals incorporated into the buildings around them. The walk traces the geologic and geographic history of the rock, and looks at the development of local quarries. This walk served as the prototype for other walks.

Point Pleasant Park provided an ideal site for a walk focusing on local geology. *A Walking Tour of Rocks, Minerals and Landforms of Point Pleasant Park* was produced in 1986 to tell the story of the area's rocks and minerals and how they influenced the history of the region.

The success of the previous walking tours spawned three new walks in 1987. *A Walking Tour of Rocks, Minerals and Building Stones of Spring Garden Road, Halifax*, concentrates on the variety of building stone and the geological and human history of this popular area. The two other walks went farther afield. *A Walking Tour of Rocks, Minerals and Landforms of Peggys Cove* looks at the sequence of geological events that produced one of the most unique areas in the world. This walk concentrates on the local granite: how it was formed, the forces that shaped it and its resource potential. Truro is the site of *A Walking Tour of Rocks, Minerals and Landforms of Victoria Park*. This walk describes how geologists interpret the varied geology and the role that water has played in shaping the rocks through erosion and deposition.

Two additional walks are tentatively being planned for 1988. Truro will be the site of a building stone walk, while another is planned for the area of the old Dartmouth Commons.

In addition to these activities, the Public Information Group answers hundreds of enquiries annually of both specific and general nature. These activities all fall within the Program mandate which is to familiarize the

public with geology, mineral resources
and mining in Nova Scotia.



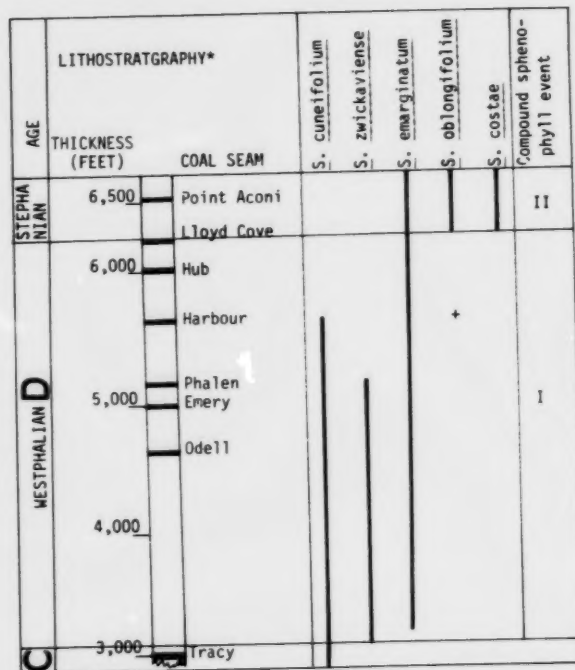
DETERMINATION OF THE WESTPHALIAN/STEPHANIAN BOUNDARY BY SPHENOPHYLL EVENTS IN THE MORIEN GROUP, SYDNEY COALFIELD, NOVA SCOTIA¹

E. L. Zodrow²

INTRODUCTION

The objective of this report is to use the revised sphenophyll data (Zodrow, in press) to locate the Westphalian/Stephanian boundary at or near the level of the Lloyd Cove Seam, Sydney Coalfield (Fig. 1).

The genus *Sphenophyllum* Brongniart ranged from Devonian to early Triassic and encompassed wedge-shaped leaflets with toothed distal margins that are attached in whorls to articulate axes and stems (Plate 1). The genus was particularly diversified in the Upper Carboniferous and in the Lower Permian where it has great biostratigraphic utility. The first reported occurrence of *Sphenophyllum* in the Sydney Coalfield, *S. erosum* and *S. schlotheimii*, was by Bunbury (1847), and Dawson (1861) added *S. antiquum*. These are synonyms of *S. cuneifolium* and *S. emarginatum*. Bell (1938), however, was the first to systematically study the genus in the Sydney Coalfield and identified *S. emarginatum*, *S. cuneifolium*, *S. majus*, *S. oblongifolium*, *S. trichomatosum*, and *S. myriophyllum*. Of these, *S. majus* was misidentified, and *S. trichomatosum* and *S. myriophyllum* could not be confirmed from the fragmentary collections. *S. oblongifolium* is a European Stephanian floral element.



*Bell (1938, Fig. 1). + Sole record.

Figure 1. Biostratigraphy of the Sydney Coalfield, Nova Scotia, based on sphenophyll events. The Shoemaker Seam is about 1,000 feet and the McAulay Seam 1,300 feet below the Tracy Seam.

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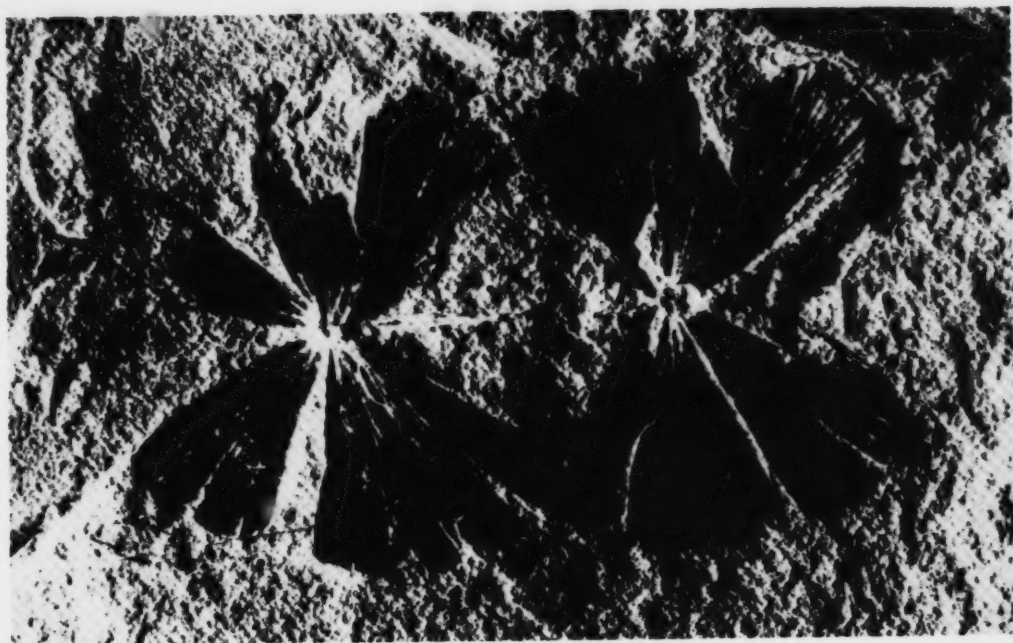


Plate 1. Photograph of top view of Sphenophyll zwickavieuse, Sydney Coalfield.

Its abundance at the Lloyd Cove Seam (in the absence of other supporting Stephanian elements) was considered by Bell (1938, p. 18) to be insufficient evidence for introducing the Westphalian-Stephanian boundary. With the development of new open pit and underground coal mines in the youngest strata at Point Aconi, extensive collections of larger contiguous sphenophyll specimens have been made for this study.

MATERIALS

The specimens are all preserved as compressions/impressions in shaly claystone to coarse siltstone, representing a range of paleoenvironments from lacustrine to deltaic proximal marine. Some of the remains, especially those from the Point Aconi area, are naturally macerated.

CONCEPTS

Form genera are in varying degrees artificial and cannot be assigned to a family, although they may be referable to a taxon of higher rank. A form taxon is, however, characterized by a number of parameters that can be explicitly stated and repeatedly observed. The nomenclature is not necessarily the most 'typical' of the taxon and the onus is on its author to describe the 'population' variation.

Paleobotanical events (rooted in homotaxis) are defined as encompassing the following:

- (1) first record of floral form taxa
- (2) their perceived abundance, an epibole
- (3) disappearance from the record

These are time-significant and reflect evolutionary changes in the biota; from

them, data can be derived for the construction of range zones. If (1) is closely connected in time with speciation, (2) reflects taxial culmination, and (3) is closely connected in time with extinction, then temporal zone precision may be very good (Johnson, 1979).

SYSTEMATIC PALEOBOTANY

Group (1): large- and small-leaved trizygioid form species.

Sphenophyllum costae (Sterzel) Teixeira, emend. Zodrow

Synonymy:

1986 Sphenophyllum costae, Zodrow, p. 312-314, Pl. 6, Figs. 1-3; Text-Figs. 9a-b, 13.

Diagnosis, emended: Fructification unknown; whorl six leaflets, trizygioid, anisophyllous; cuneate leaflets vary in length from 10-20 mm and in width at distal margin from 5-15 mm (Fig. 2a); distal margin curved with obtuse and acute tooth forms (heterodentate, Fig. 3, a vs. b); a single vein enters leaflet base thereafter dichotomizing up to four times before reaching distal margin.

Vertical range: In the Carboniferous of Canada, S. costae has only been identified from the Sydney Coalfield where it ranges from the Lloyd Cove Seam to the highest strata at Point Aconi (Fig. 1).

Sphenophyllum oblongifolium (Germar et Kaulfuss) Unger, emend. Barthel

Synonymy:

1938 Sphenophyllum oblongifolium, Bell, p. 91, Pl. 94, Figs. 3, 6 and 7.

1982 Sphenophyllum oblongifolium, Zodrow, p. 597 (nomen).

1986 Sphenophyllum oblongifolium, Zodrow, p. 314, 321-323, Fig. 13 (nomen).

Diagnosis: Strongly heterophyllous; whorl six leaflets, anisophyllous, plagiotropic; leaflets bluntly cuneate, convex lateral margin, maximal

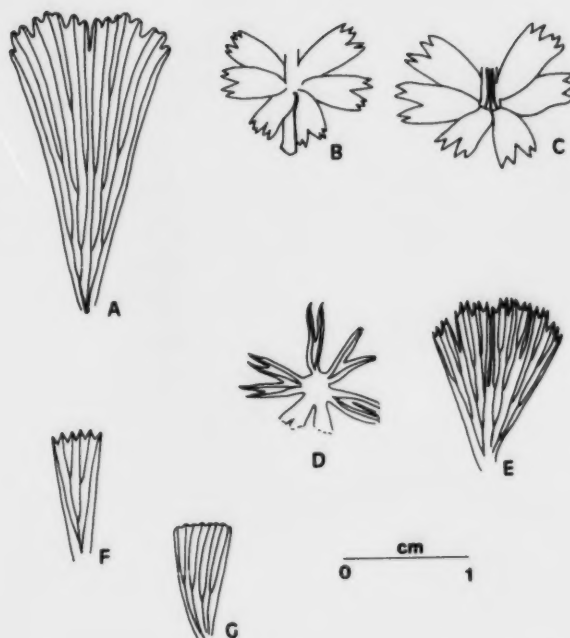


Figure 2. Sphenophylls of the Sydney Coalfield, Nova Scotia: (A) S. costae with obtuse teeth; (B) and (C) S. oblongifolium illustrating trizygioid whorls (i.e. pairs of leaflets of differing lengths); (D) and (E) S. zwickaviense, where (D) illustrates an anisophyllous whorl; (F) S. cuneifolium; (G) S. emarginatum.

width at 2/3 leaflet length; distal margin with 4-8 pointed teeth (Fig. 2b-c).

Vertical range: One record is from the Harbour Seam. At the Lloyd Cove Seam the species is very abundant and remains so to the top of the Morien Group at Point Aconi.

Group (2): Large- and small-leaved non-trizygioid form species

Sphenophyllum zwickaviense Storch

Synonymy:

1938 Sphenophyllum majus, Bell, p. 90, Pl. 94, Fig. 1

1980 Sphenophyllum oblongifolium,

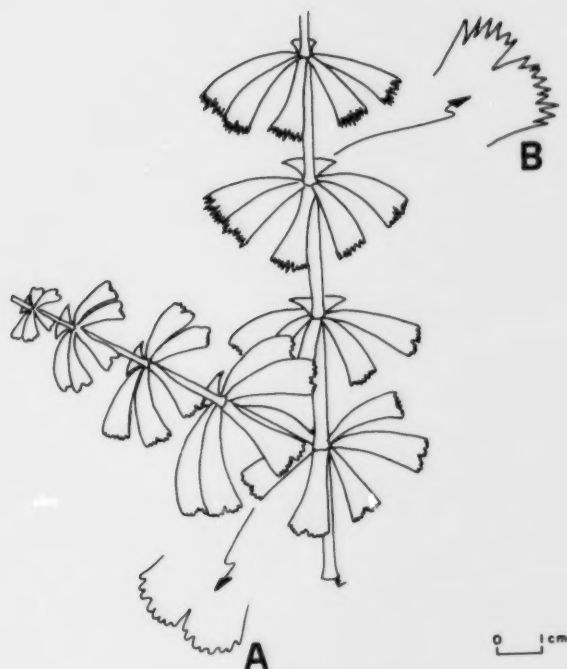


Figure 3. Partial reconstruction of the vegetative morphology of *S. costae*, illustrating the heterodentate tooth configuration (A vs. B).

Zodrow and McCandlish, p. 78, Pl. 112, Fig. 2.

1985 *Sphenophyllum zwickaviense*, Zodrow and Cleal, p. 1469, Fig. 4 (nomen).

1986 *Sphenophyllum zwickaviense*, Zodrow, p. 310, Pl. V, Fig. 1; Figs. 8a-c.

Diagnosis: Whorl six leaflets (Pl. 1); leaflets heterophyllous, anisophyllous, up to 14 mm long and 10 mm wide at distal margin, deeply cleft; lateral margin straight; distal margin convex with up to 24 acute-triangular teeth and obtuse-pointed sinuses between them (Fig. 2d-e).

Vertical range: The earliest record of the form species is from the Tracy Seam (basal Westphalian D), and the last from the Phalen Seam. It is particularly abundant at the Emery and the Odell Seams.

Sphenophyllum cuneifolium (Sternberg) Zeiller

Synonymy:

1847 *Sphenophyllum erosum*, Bunbury (non Lindley et Hutton), p. 430, Pl. 23, Figs. 3A-B.

1861 *Sphenophyllum antiquum* n. sp. Dawson, p. 170-171, Figs. 7a-b.

1868 *Sphenophyllum erosum*, Dawson (non Lindley et Hutton), p. 480, Fig. 165 C and Cl.

1938 *Sphenophyllum cuneifolium*, Bell, p. 89, Pl. 92, Figs. 6-8.

1980 *Sphenophyllum cuneifolium*, Zodrow and McCandlish, p. 75, Pl. 107, Fig. 1; Pl. 109, Fig. 3; non Figs. 1-2.

Diagnosis: Leaflets polymorphic, slender cuneate, up to 15 mm long and 10 mm wide at distal margin; lateral margin slightly convex; distal margin straight, slightly arcuate with teeth and sinuses equilateral-triangular in shape (Fig. 2f).

Vertical range: The range given by Bell (1938; Fig. 1), from the Shoemaker to the Emery Seams, is now significantly extended, from the McAulay to the Harbour Seams.

Sphenophyllum emarginatum (Brongniart) Brongniart

Synonymy:

1847(?) *Sphenophyllum schlotheimii*, Bunbury, p. 430 (nomen).

1866 *Sphenophyllum* sp. Dawson, Pl. 12, Fig. 58.

1938 *Sphenophyllum emarginatum*, Bell, p. 89, Pl. 93, Figs. 1 to 3.

1938 *Sphenophyllum oblongifolium*, Bell, p. 91, Pl. 94, Fig. 5; Pl. 95, Figs. 1-2.

1962 *Sphenophyllum emarginatum*, Bell, p. 46-7, Pl. 44, Figs. 1, 3, and 4; Pl. 56, Fig. 1.

1966 *Sphenophyllum emarginatum*, Bell, p. 60, Pl. 29, Fig. 2; p. 74, Pl. 36, Figs. 5, and upper two-whorled specimen of Fig. 6.

1966 *Sphenophyllum oblongifolium*, Bell, p. 74, Pl. 36, Fig. 4 (same as in Bell, 1969, p. 15).

1969 *Sphenophyllum emarginatum*, Bell, p. 15 (nomen). 'Pl. 31, Figs. 5, 6, and

7' is printing error, it should read: Pl. 36, Figs. 5 and 6.

1978 *Sphenophyllum emarginatum*, Zodrow and McCandlish, Table 4 (nomen).

1978 *Sphenophyllum majus*, Zodrow and McCandlish, Table 4 (name).

1978 *Sphenophyllum oblongifolium*, Zodrow and McCandlish, Table 4 (nomen).

1978 *Sphenophyllum cuneifolium* Zodrow and McCandlish, Table 4 (nomen).

1980 *Sphenophyllum emarginatum* Zodrow and McCandlish, p. 75, Pl. 110, Figs. 1-3.

1980 *Sphenophyllum majus* Zodrow and McCandlish, p. 77, Pl. 111, Figs. 1-3.

1980 *Sphenophyllum oblongifolium* Zodrow and McCandlish, p. 78, Pl. 112, Figs. 1 and 3.

1982 *Sphenophyllum majus*, Zodrow, p. 597 (nomen).

1986 *Sphenophyllum emarginatum*, Zodrow, p. 320 (nomen).

Diagnosis: Whorl 6-9 leaflets; leaflets heterophyllous, cuneate up to 17 mm long and 10 mm wide at distal margin; distal margin curved, seldom cleft with round teeth (Fig. 2g).

Vertical range: A long-ranging sphenophyll encompassing the entire strata of the Sydney Coalfield.

BIOSTRATIGRAPHICAL CONCLUSIONS

Based on a 140 year history of megafloal collecting, the most detailed evidence for the sphenophyll distribution in the Canadian Carboniferous is from the Sydney Coalfield. This study summarizes the fact that only five species are recognizable: *S. cuneifolium*, *S. costae*, *S. emarginatum*, *S. oblongifolium*, and *S. zwickaviense*. *S. cuneifolium* and *S. zwickaviense* reach an appropriate common youngest age in the presence of *S. emarginatum*. This represents compound paleobotanical event I (Fig. 1). Event II, comprises the common first occurrences of *S. oblongifolium* and *S. costae* subsequent to event I. On comparison with European sphenophyll events, summarized

most recently by Storch (1984), events I and II are recognized as a 'signature' at the basal Stephanian. Hence, the signature is an important biostratigraphic argument and can be used as an index for locating the Westphalian/Stephanian boundary at or near the Lloyd Cove Seam (Fig. 1). There is additional biostratigraphic evidence from the odontopterids (Zodrow, 1985) to suggest that the basal Stephanian represents the Cantabrian time span as defined by Wagner (1972). Hence, locating boundaries on the basis of the sphenophyll events should be tested very critically for world-wide consistency.

In comparison to the European Upper Carboniferous, where more than 40 sphenophylls are documented and circumscribed (Storch, 1984), it is concluded that the genus is undiversified in Canadian rocks of the same age (Zodrow, 1988).

ACKNOWLEDGMENT

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SEISMIC STRATIGRAPHY OF PART OF THE UPPER NOVA SCOTIAN CONTINENTAL SLOPE: A PROGRESS REPORT¹

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ABSTRACT

Fifteen seismic profiles totalling 355 km are being used to study the late Mesozoic and Cenozoic seismic stratigraphy of part of the upper continental slope off central Nova Scotia. The study area, covering about 1400 km², has one exploratory well.

Five major sequences defined by five seismic unconformities reveal a general basinward shift and progradation of the paleoslope environment. A major unconformity at the base of the study interval separates Upper Jurassic and Lower Cretaceous carbonates from overlying dominantly clastic sediments. These clastic sequences terminate at the Cretaceous-Tertiary unconformity. The next sequence exhibits a variety of seismic facies that may relate to Vail's (1987) low stand systems tract. This is unconformably overlain by a high stand systems tract, which is overlain by another low stand systems tract. The uppermost sequence is a wedge of Quaternary clastics.

INTRODUCTION

This progress report on seismic stratigraphy is concerned with the Late Mesozoic and Cenozoic stratigraphy and geological history of a portion of the western-central part of the upper continental slope which lies within the Scotian Basin off Nova Scotia. The study area extends from latitude 42°34' to 42°49'N and longitude 62°50' to 63°30'W and covers an area of about 1400 km². Water depth ranges from 285 to about 1700 m (Fig. 1). Thirteen migrated, north-south seismic reflection profiles, approximately 20

km long, which were shot by Texaco Canada Ltd. in 1980 and released by the Canadian Oil and Gas Lands Administration (COGLA), form the main data for this study (Fig. 2). They cover a total distance of about 270 km. Two east-west unmigrated seismic reflection profiles shot by Texaco Canada Ltd. in 1981 and covering a total distance of about 85 km within the study area provided strike control for tying in reflections between adjacent north-south dip lines (Fig. 2). In total, the 15 seismic reflection profiles cover a distance of about 355 km. Well cuttings from the

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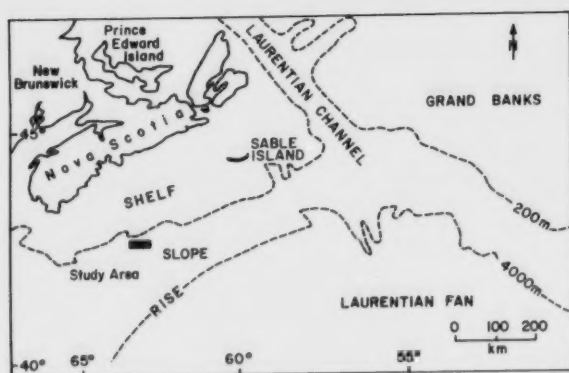


Figure 1. Index map showing generalized bathymetry and location of study area (black rectangle) on the upper continental slope off central Nova Scotia.

1984 Petro-Canada Texaco et al. Albatross B-13 well ($42^{\circ}41'11''$ N, $63^{\circ}02'12''$ W) were also studied to correlate various reflectors to their respective lithologies. Preliminary biostratigraphic data (Bujak Davies Group, 1988) are being used to determine the ages of various reflectors. Although the study area has a limited number of exploratory wells, interpolation between seismic lines is considered reliable because these lines are relatively closely spaced, averaging 6.4 km and ranging from 3.6 to 11.8 km apart.

The 13 north-south profiles (Fig. 2) which form the main basis for this progress report were recorded by a DFS-5 instrument system connected to a 3200 m detector cable. The geophones were of type T.I acceleration cancelling and were towed at 15 m below sea level. The cable configuration constituted 96 groups containing 20 geophones per group and spaced at 1.66 m. The source was a 66.8 l (4075 cubic inch) tuned air gun array that was towed 7 m below sea level. The shot point and group intervals were 33.33 m, resulting in 48 fold stack coverage. The 7 second records were recorded at a 4 ms^{-1}

sampling rate. The records were filtered at 8-64 Hz. Position control was based on an Argo Survey System and a secondary Loran C Survey.

PREVIOUS WORK

The Scotian Basin began to form during the opening of the Atlantic Ocean in the Late Triassic (Jansa and Wade 1975). McIver (1972) and Jansa and Wade (1975) gave a broad and generalized description of the outer Scotian shelf. Jansa and Wade (1975) also provided a stratigraphic overview using seismic profiles to define the stratigraphy and structural trends of the east coast margin. Eliuk (1978) used seismic profiles and well control to study deposition and diagenesis of the Abenaki Formation, a Jurassic carbonate platform. Given (1977) and Swift (1987) studied the development of the continental margin from the Jurassic carbonate platform to the Quaternary and recognized several unconformities. King and Young (1977) studied continental slope seismic profiles, and noted constructional and destructional phases of continental margin development. Emery and Uchupi (1967), Jansa and Wade (1975) and Given (1977) also noted that the continental margin grew seaward during the Tertiary. Recent work on the Late Cenozoic section includes seismic interpretations by Hill (1984), Swift (1985), Piper et al. (1987), Piper and Sparkes (1987) and Swift (1987).

Pleistocene strata unconformably overlie Tertiary sediments (King and MacLean, 1976; Piper and Sparks, 1987). The Banquereau Formation of Tertiary and uppermost Cretaceous age sediments underlies the surficial sediments and consists of several shale units that thicken seaward (McIver, 1972). It extends down to the top of the Wyandot chalk in this area, approximately 100 m below the Cretaceous-Tertiary boundary. The Cretaceous is represented at the paleoshelf edge by several clastic and thin carbonates which have clastic

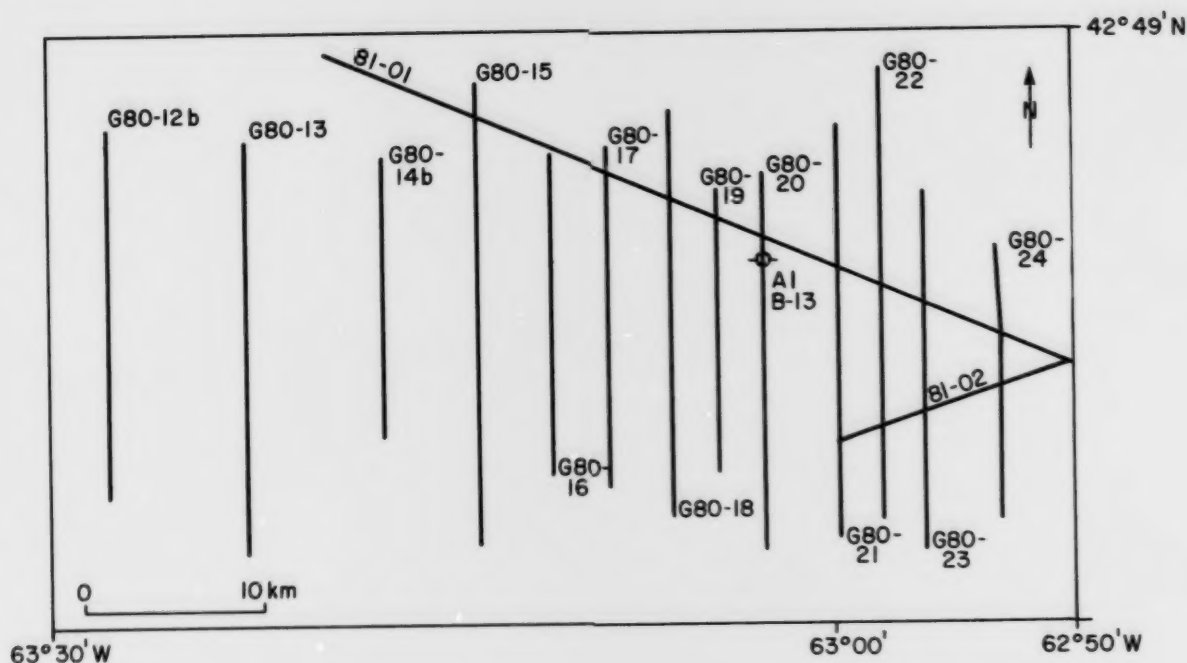


Figure 2. Location and coverage of 15 seismic profile lines and location of Albatross B-13 well within the study area: G80-12b to G80-24, north-south seismic reflection profiles shot in 1980; 81-01 and 81-02, east-west seismic reflection profiles shot in 1981; Al B-13, Albatross B-13 well.

lateral equivalents shoreward and seaward (Wade and MacLean, in press).

SEQUENCE ANALYSIS

INTRODUCTION

Five major sequence boundaries defined by five seismic unconformities (Fig. 3, A-E) and the sea floor have been recognized and interpreted from patterns of reflection terminations categorized as onlap, downlap, toplap or truncation (Vail, 1987). The sequence boundaries so delineated were then followed over each section, including parts where the reflections were conformable to the boundary, and tied throughout the seismic grid.

The extent and configuration of the unconformities and sequences for sections G80-12b to G80-20 (Fig. 2) are

closely comparable. Because line G80-12b is representative of this group and the clearest profile, it is described in detail. The sections east of line G80-20 are somewhat different and are not described in this report.

SEISMIC UNCONFORMITY E

Seismic unconformity E is the oldest unconformity recognized within the study area. It occurs at the top of the Upper Jurassic and Lower Cretaceous carbonates and is traceable basinward along a strong reflector (Figs. 3 and 4). This unconformity probably separates carbonates and their time equivalents from the predominantly clastic sediments above. Reflections from strata above this seismic unconformity form relatively uniform patterns. Basinward, these reflectors are conformable to this surface and

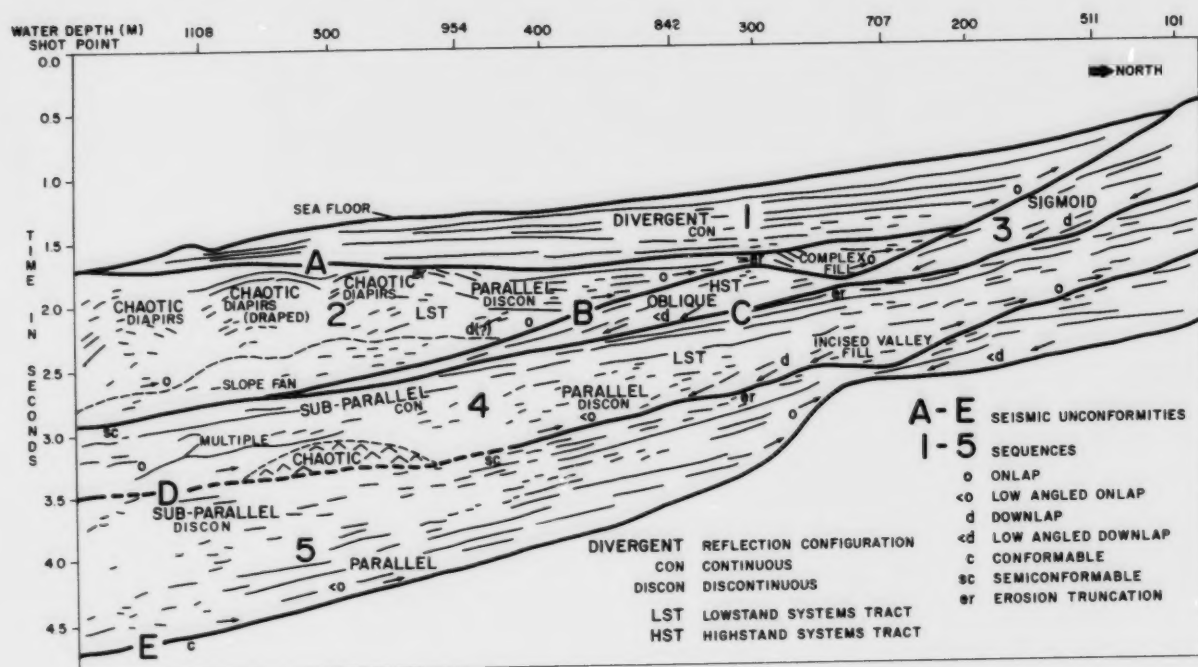


Figure 3. Interpreted seismic reflection profile G80-12b shown in Figure 4. Vertical axis is two-way travel time.

then onlap it northward at low angles that progressively increase upslope toward the paleoshelf break. Shoreward of the paleoshelf break, reflectors overlying unconformity E downlap it at low angles. Farther shoreward, the reflectors over this surface are conformable to it.

SEISMIC UNCONFORMITY D

Seismic unconformity D is recognizable by prominent downlapping and onlapping of reflectors. An onlap relationship of the reflections within sequence 4 overlying unconformity D is observable in all sections on a possible paleoslope. The unconformity is obscured basinward by a chaotic reflector pattern above it. Shoreward of the paleoshelf edge, the reflectors typically exhibit a low-angled downlap not exceeding 10°. Farther up the paleoslope, the reflectors overlying unconformity D onlap at low angles (10° to 15°).

SEISMIC UNCONFORMITY C

Unconformity C has a short lateral extent within the study area, commonly covers only half of each profile where it is present, and is observable in most sections as a downlap surface (Figs. 3 and 4). Reflections from the overlying beds (sequence 3) form a low-angle downlap (5°). To the north, the reflections from the overlying beds are conformable and the unconformity is delineated by tracing the reflector. This seismic event is not present in sections G80-23 and G80-24.

SEISMIC UNCONFORMITY B

Unconformity B is easily recognized by onlap of the reflectors from the beds above (sequence 2) throughout most of its length. There is an initial low-angle (5° to 10°) onlap seaward exhibited by relatively strong continuous reflectors. Farther upslope, the onlap angle increases

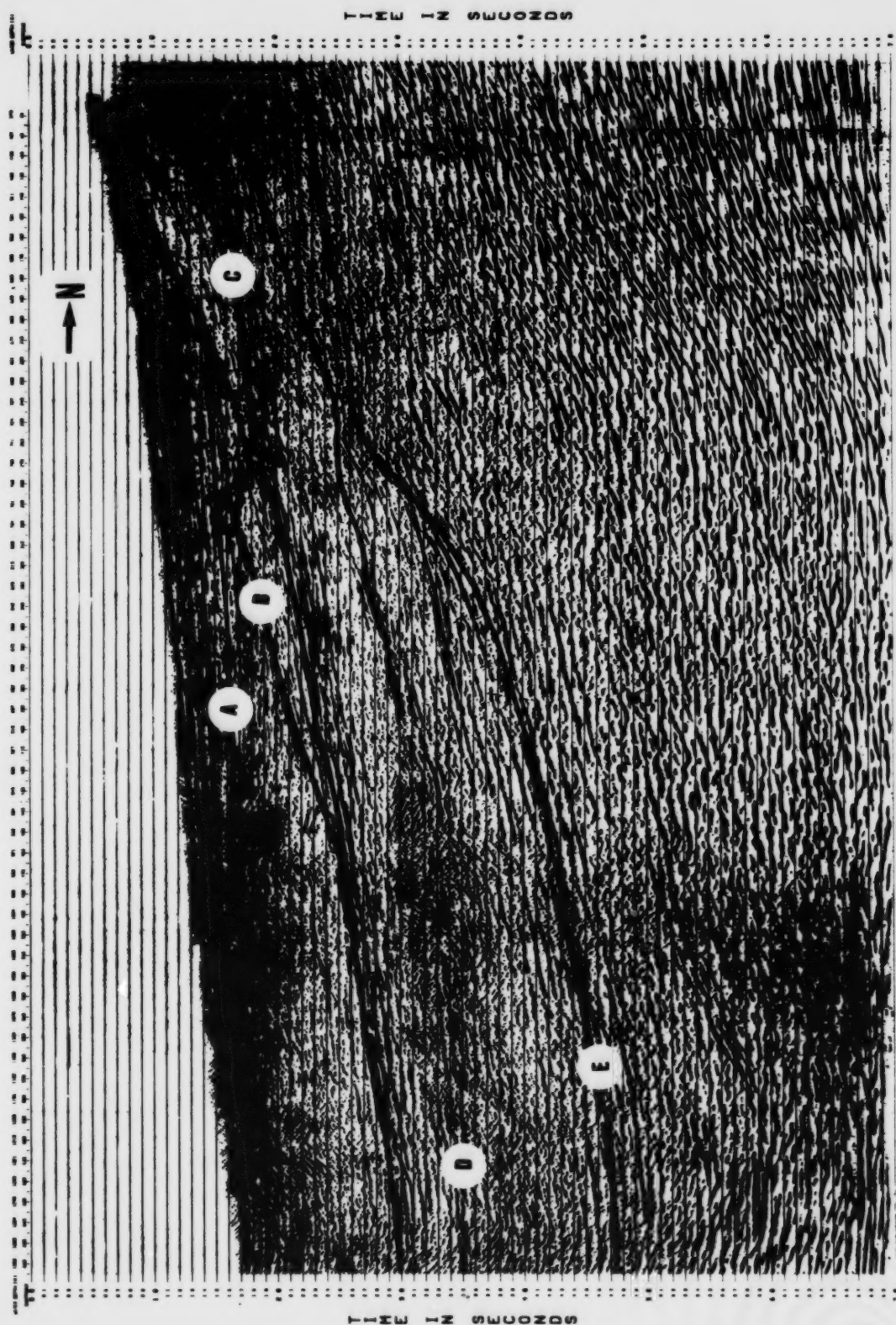


Figure 4. Seismic reflection profile G80-12b. See Figure 2 for line location. Vertical axis is two-way travel time.

slightly to approximately 10°. A possible paleochannel is suggested still farther upslope by reflectors indicating erosional truncation below, and a complex fill above unconformity B (Fig. 3). At a water depth of about 440 m, unconformity B is truncated by the present sea floor.

SEISMIC UNCONFORMITY A

Unconformity A is the youngest major seismic unconformity within the study area. It is indicated by both erosion and contrasting reflection configurations. Erosional truncation of the underlying reflectors is evident along most of its length. Some sections show considerable relief of the unconformity surface where it appears to drape over diapiric shale structures (Piper and Sparkes, 1987) (Fig. 3). This seismic unconformity also separates highly continuous reflectors with a divergent configuration from underlying discontinuous reflectors with a parallel reflection configuration (Fig. 3). The unconformity terminates upslope where it merges onto unconformity B (Figs. 3 and 4) and appears to correlate with the unconformity that separates units C and D of Hill (1984), which was also recognized by Piper and Sparkes (1987).

DISCUSSION

An objective seismic facies analysis reveals various systems tracts as defined by Vail (1987). These are recognized on the basis of bounding surfaces, their position within the sequence, and by geometry and facies associations (Van Wagoner et al., 1987). A low stand systems tract (LST) is evident within seismic sequences 2 and 4 (Fig. 3). In both cases a possible slope fan is implied at the base of the paleoslope, although it is highly obscured within sequence 4 by multiples from a diapiric zone in

sequence 2 above. Shoreward of this slope fan facies, there is a possible low stand wedge that onlaps farther up against a paleoslope. Erosion is indicated by complex channel/valley fill at the paleoshelf edges. The upper bounding surface for sequence 4 is a downlap surface for a high stand systems tract (HST) within sequence 3 and is characterized by oblique and sigmoidal progradational reflection configurations (Figs. 3 and 4). Seismic sequence 5 may be a LST where the unconformity surface was not exposed to subaerial erosion and sequence 1 may be a LST representing Quaternary deposition associated with multiple sea level changes. A transgressive systems tract (Van Wagoner et al., 1987) was not recognized in the study area.

FUTURE WORK

A regional and more detailed facies analysis which will involve delineating different seismic facies and the construction of seismic facies maps (Brown and Fisher, 1980) is in progress. The distinguishing facies characteristics to be studied include reflection configurations, reflection amplitude and frequency, bounding relationships and external geometry.

Geophysical logs and well cuttings of the Albatross B-13 well (Fig. 2) and the nearby Shelburne G-29 well (42°38'27"N 63°33'33"W) will be studied concurrently and should provide lithologic control for the major reflectors and aid in the interpretation of depositional environments. Other seismic data expected to be released soon may enable a landward extension of the facies recognized herein.

Ages from paleontological data should enable local and regional cycles of relative sea-level change to be recognized and compared to global sea-level changes.

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THE CUMBERLAND GROUP-PICTOU GROUP TRANSITION IN THE ATHOL SYNCLINE, WEST-CENTRAL CUMBERLAND BASIN, NOVA SCOTIA¹

A. J. Deal²

An investigation of the central portion of the Athol Syncline was initiated during the 1987 field season as part of the Cumberland Basin Project. The Athol Syncline is a broad, gently folded, east-northeast-erly trending structure that dominates the western portion of the Cumberland Basin (Fig. 1). The study area is adjacent to the Springhill coalfield and consists mainly of strata assigned to the Late Carboniferous Cumberland Group (Bell, 1944). The Athol Syncline is bounded to the north by the Minudie Anticline and to the east by the Black River Diapir at the western end of the Malagash Anticline. Along the southern margin of the Athol Syncline, strata of the Cumberland Group onlap the pre-Carboniferous basement of the Cobequid Highlands Massif. The Athol Syncline extends westward from Springhill under Chignecto Bay. Its relationship to the northeast-trending structures in New Brunswick is not clear. The radical change in structural orientation, from east-west in Nova Scotia to northeast-southwest in southern New Brunswick, suggests the presence of a major structural re-orientation under Chignecto Bay.

Strata of the Athol Syncline have been tentatively divided into the following six lithostratigraphic units: (1) Polly Brook Formation, (2) Joggins

Formation, (3) Springhill Mines Formation, (4) Ragged Reef Formation, (5) Malagash Formation and (6) Balfron Formation (Ryan, personal communication). These lithostratigraphic units are mappable and a formal nomenclature will be introduced based on biostratigraphic ages, sedimentological characteristics and contact relationships. On the northern limb of the syncline the Ragged Reef Formation overlies coal-bearing strata of the Springhill Mines and Joggins Formations. The Ragged Reef Formation is composed of grey and greenish-grey sandstone with intercalated red and grey mudrock. The strata of the Ragged Reef Formation exposed on the southern limb of the syncline comprise red and grey polymictic conglomerate, grey arkosic sandstone, and minor red and grey mudrock. This unit onlaps the older, dominantly red conglomerate and sandstone of the Polly Brook Formation and basement rock of the Cobequid Highlands Massif along the southern margin. Detailed examination of the contact relationships, subsurface extent and biostratigraphy of the Ragged Reef Formation will determine the exact nature and causes of lithological variation. This unit is overlain by red and greenish-grey sandstone and mudrock of the Malagash Formation. Fine grained red sandstone

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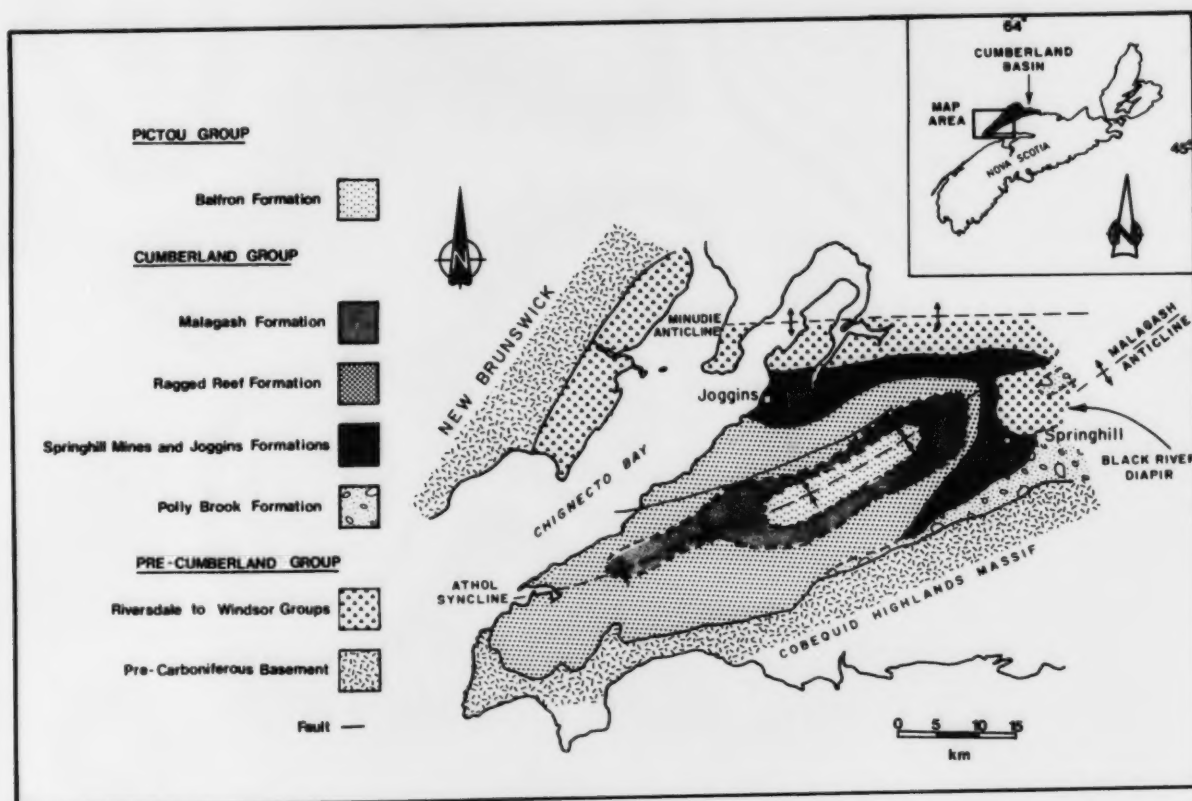


Figure 1. Geological map of the Athol Syncline area, Cumberland Basin.

and mudrocks of the Balfour Formation (Pictou Group) are exposed in the central core of the Athol Syncline and probably interdigitate with the underlying Malagash Formation.

Paleocurrent patterns on the regional scale are polymodal, with different modes occurring in different formations. Sediment dispersal patterns were determined from paleocurrent data measured principally from trough crossbedded sandstone. Data from both the Ragged Reef and Malagash Formations exposed in the north suggest a southeast paleoflow direction toward the axis of the syncline and a sediment source area in the west or northwest. On the south limb of the syncline, data obtained

from the Ragged Reef Formation indicate a north to northwest sediment dispersal trend with a source area located to the south, presumably the Cobequid Highlands Massif. A northeast sediment dispersal trend is observed in the Balfour Formation along the axis of the syncline, however this is based on a limited number of paleocurrent measurements.

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SULPHUR ISOTOPIC COMPOSITION OF SULPHIDES IN MEGUMA GOLD DEPOSITS: IMPLICATIONS FOR GENETIC MODELS¹

D. J. Kontak and P. K. Smith

Base metal sulphides (Fe, Cu, Zn, Pb) are a persistent, although volumetrically minor phase in auriferous quartz veins hosted by the Cambro-Ordovician Meguma Group metasediments of southern Nova Scotia. The paragenesis of the sulphides is such that they bracket the gold mineralizing event, providing an opportunity to examine the ambient physio-chemical conditions of the ore fluid during mineralization. In this study, 45 sulphides (16 py, 4 po, 1 galena, 24 arspy) from eight deposits in the eastern Meguma Terrane have been analyzed for $\delta^{34}\text{S}$, with 32 analyses for the Beaver Dam deposit (3 million tons, 0.29 oz/ton).

$\delta^{34}\text{S}$ values for sulphides from Beaver Dam are as follows: py (N=16) = $9.9 \pm 1.1\text{‰}$; po (N=4) = $9.9 \pm 0.2\text{‰}$; arspy (N=11) = $10.5 \pm 0.4\text{‰}$; galena = 9.4‰ . No systematic variation of $\delta^{34}\text{S}$ was noted for any sulphide regardless of paragenetic stage or morphology. For the remaining 7 deposits, 13 arspy analyses range from 9.8 to 25.0‰ with small intra-deposit variations (e.g., Fifteen Mile Stream $12\text{--}14.8\text{‰}$ for 3 analyses). Additional analyses by Sangster (1987) for a further 3 deposits show a similar provinciality for $\delta^{34}\text{S}$ values for sulphide mineralization.

The sulphide assemblages of the gold deposits, in addition to organic C in the wall rocks and CO_2 -bearing fluid inclusions hosted by quartz, indicate ambient oxidation conditions prevailed below the $\text{H}_2\text{S}/\text{SO}_2$ boundary. Thus, $\delta^{34}\text{S}$ mineral is a good approximation of $\delta^{34}\text{S}$ fluid. The tight intra-deposit clustering of data indicates $f\text{O}_2$ remained below this boundary condition and excursions related to changing Eh, pH and/or T°C were either short lived or nonexistent.

The $\delta^{34}\text{S}$ fluid ($9\text{--}25\text{‰}$, average 15‰) for the Meguma gold deposits and provinciality of the data provides constraints for potential source reservoirs and, therefore, genetic models. The syngenetic, exhalative model is considered unlikely and direct magmatic emanations can be

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eliminated as the dominant source of sulphur. A model involving the incorporation of variable proportions of greywacke-and shale-derived sulphur from Meguma sediments is preferred with greywacke sulphur more abundant. The small intra-deposit variability of $\delta^{34}\text{S}$ fluid is interpreted to reflect high fluid/rock ratios, a feature also suggested by extensive alteration haloes. This latter feature may favour a non-Meguma Group reservoir as the ultimate source of the fluids.

"CRACK-SEAL" VEINS IN MEGUMA LODE GOLD DEPOSITS: HYDRAULIC FRACTURING OR REPLACEMENT PHENOMENON¹

P. K. Smith and D. J. Kontak

Auriferous quartz veins hosted by Lower Paleozoic turbiditic sediments of the Meguma Group have produced in excess of 1,000,000 oz. of gold from approximately 60 districts. Essentially all of this production has come from shallow development (<300 metres) between 1860-1940 using antiquated mining techniques.

Numerous vein types occurring at all gold deposits exhibit differing morphology, texture, mineralogy and relative age which, in many areas, can be related to the variability of local wall-rock texture and composition. Most veins display complex, composite textures which suggest episodic fluid emplacement along structurally favorable dilatant zones. Of these, the most problematic of the vein types, in terms of genesis, are the "crack-seal" or "laminated" quartz veins which carried much of the recovered historical gold. Recently, separate studies have suggested several distinct mechanisms for their origin, including: (i) syn-sedimentary siliceous oozes; (ii) pre-fold, hydraulic fracture filling induced by high pore-fluid pressure and (iii) variable wall-rock replacement. The absence of any convincing evidence of syn-sedimentary vein formation severely limits the first theory, while relative structural age relationships suggesting that stratigraphy was locally upright prior to initial vein formation raises problems with regard to the second hypothesis.

Underground geological mapping of the Beaver Dam gold deposit suggests that relatively constant stratigraphic thickness is maintained regardless of the amount of vein material present. In some greywacke beds, irregular granular textured quartz veins are formed by wall-rock replacement representing the end products of extreme silicification. In slate lithologies, vein textures are generally dominated by either massive, crystalline white quartz, "crack-seal" laminated type quartz or a combination thereof. It is not uncommon to observe replacement veins in greywacke

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interconnecting with "crack-seal" type veins in adjacent slate beds, but in such cases relative age relationships become obscured. Because no significant thickening in the stratigraphy occurs in areas of quartz veining, we conclude that "crack-seal" type veins are formed in part or in whole by selective wall-rock replacement. Petrographic studies of these vein types lend corroborating evidence and indicate that the fine, dark laminae typical of these veins are stylolitic in nature. As the model proposed herein predicts, the laminae in the "crack-seal" veins represent the most insoluble wall-rock residue.

GEOCHEMISTRY OF ALKALI FELDSPARS, SOUTH MOUNTAIN BATHOLITH, NOVA SCOTIA: IMPLICATIONS FOR PETROGENESIS¹

D. J. Kontak

The geochemistry of granitoid rocks is a poor approximation of the bulk composition of the melt from which the constituent minerals crystallized. A multitude of processes (e.g., filter pressing, accumulation, accumulate growth, subsolidus fluid interaction) may act singularly or collectively to modify the original bulk composition of the melt and crystals. One way to circumvent this problem is by direct analysis of mineral phases which have retained their primary, magmatic compositions. Assuming that melt-crystal evolution for a given element (K_D) remained constant during magmatic crystallization, mineral chemistry should then provide a more direct and reliable means of evaluating the geochemical evolution of magmatic systems.

Alkali feldspar (Kf) separates from the South Mountain Batholith, representing the most primitive to most evolved members, were analyzed for major and trace (Rb, Sr, Ba, Li, Ga, Pb, Cs, Nb, Mo, Zr, Th, U, W, Y, REE) elements to examine the geochemical evolution of the batholith. Results are summarized as follows: (1) bulk, magmatic compositions and calculated minimum temperatures (for 1 Kbar) for the major units are: granodiorites (grnd) Or₇₀₋₇₅, 650-725°C; monzogranites (mnzg), Or₅₈₋₆₅, 650-700°C; pegmatites, Or₆₈₋₇₈, 525-400°C; (2) there is a consistent trend of increasing phosphorous (wt. %) in Kf from grnd (0.05-1.0) to mnzg (0.18-0.35), to pegs in mnzg (0.44-0.52) to large pegs (0.56-1.08); (3) all samples conform to single, well-defined trends on Rb vs. Sr and Rb vs. Ba plots, suggesting a crystal chemical control and constant K_D 's; (4) Kf from grnds show large variations (ppm) in Sr (350-220) Ba (7000-3500), Eu/Eu (4-13) and Σ REE and Eu/Eu decrease consistently from grnd pegs are chemically the most variable, reflecting primarily the degree of fractionation of their parent melt.

Some important conclusions that provide constraints for petrogenesis of the batholith are: (1) grnds do not represent homogeneous parental melts; (2) grnds cannot be parental to

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all mnzgs: (3) some significant chemical differences between mnzg suites occur indicating multiple, co-existing melts; (4) P behaves as an incompatible element during fractionation with late-stage enrichment in pegs; (5) LREE's decrease systematically during fractionation mainly due to sequestering of LREE into accessory phases and Eu into feldspar; (6) trace element (Rb, Cs, Li, REE) contents of pegmatitic Kfs are excellent indicators of degree of fractionation (and mineral potential).

In addition to the above, one of the more significant results of this study that will be demonstrated is that chemical differences between suites not readily apparent using whole rock chemistry are more obvious utilizing mineral chemistry. This is due mainly to the lack of dilution which occurs during whole rock analyses of granites, which typically contain 30-45 vol. % quartz.

LEUCOGRANITE AND LEUCOMONZOGROGRANITE IN THE SOUTH MOUNTAIN BATHOLITH, SOUTHWESTERN NOVA SCOTIA¹

M. A. MacDonald, M. C. Corey, L. J. Ham and R. J. Horne

Light-coloured, chemically evolved, post-tectonic granitoid rocks (LCGR) are frequently found to be spatially associated with Sn, W, U ($\pm$ polymetallic) deposits in many Paleozoic fold belts of the world. In fact, LCGRs are often considered to be the progenitors in these terrains. Thus, it is important to have a well defined system for identifying and describing these LCGRs which can be readily and meaningfully applied in regional geological mapping programs.

Traditionally, such terms as leucogranite, alaskite, leucomonzogranite and leucadamellite have been used interchangeably to describe LCGRs of the South Mountain Batholith (SMB) of Nova Scotia. Most publications have noted the "relative absence" of mafic minerals and have summarized some of the petrographic and geochemical characteristics of these rocks, but prior to this study no definition of leucogranite has been proposed.

A classification scheme based upon the abundance of mafic minerals (i.e. biotite, chlorite replacing biotite, cordierite and garnet) has been developed for the geological mapping of the SMB. Leucogranite and leucomonzogranite are presently defined as rocks containing 0-2% and 2-6% mafic minerals, respectively. Both rock types contain appreciable amounts (generally 3-10%) of muscovite and may contain accessory andalusite, fluorite, topaz, tourmaline and opaques (sulphides). Recent geological mapping indicates that the eastern portion of the SMB contains approximately 1% leucogranite, 10% fine- to medium-grained leucomonzogranite and 25% medium- to coarse-grained leucomonzogranite.

In this study we focus on the modes of occurrence and associated mineralization of the leucogranitic rocks.

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Leucogranites occur:

(1) as discrete intrusive bodies ($<1.5 \text{ km}^2$) and as dykes, small plugs ($<100 \text{ m}$) and isolated outcrops. These leucogranites are hosted primarily by leucomonzogranite and, to a lesser extent, by monzogranite and granodiorite; textures include equigranular, porphyritic, aplitic, pegmatitic and seriate. Sharp intrusive contacts with host rocks (exposed and inferred) and the rare occurrence of xenoliths of other granitoid phases indicate that these leucogranitic rocks were of magmatic origin.

(2) as alteration zones (i.e. via conversion of biotite to white mica) within fine- to medium-grained leucomonzogranite bodies; textures are primarily equigranular or porphyritic and reflect the texture of the host rock; associated greisenization and/or hematization are common; leucogranite occurs throughout leucomonzogranite bodies, and also in embayments and near granite/granite or granite/metasediment contacts.

Numerous mineral occurrences/deposits (e.g. East Kemptville, Long Lake, Millet Brook) are spatially and presumably genetically associated with leucogranitic rocks. However, the apparent absence of these rocks (at the present level of erosion) at other occurrences/deposits implies that leucogranite may not always be an essential ingredient for mineralization in the SMB.

PRIMARY AND SECONDARY STRUCTURAL FEATURES IN THE EASTERN PORTION OF THE SOUTH MOUNTAIN BATHOLITH: IMPLICATIONS FOR REGIONAL STRESS ORIENTATIONS DURING INTRUSION¹

R. J. Horne, M. C. Corey, L. J. Ham and
M. A. MacDonald

Schlieren banding, megacryst-xenolith alignment and biotite parallelism, indicative of primary magma flow, displaying concentric, random and linear patterns in the South Mountain Batholith (SMB) reflect intrusive geometry. In the easternmost part of the batholith patterns reflect differential flowage near intrusive contacts. However, in the east-central portion of the batholith preferred linear trends may, in part, reflect syn-tectonic stress during intrusion.

Statistical evaluation of 3600 joints within the eastern portion of the SMB has identified six distinctive joint sets (trends), all steeply dipping: Trend 1, 040°; Trend 2, 056°; Trend 3, 063°; Trend 4, 128°; Trend 5, 146°; Trend 6, 164°. The dominant joint sets, trends 3 and 5, form a nearly orthogonal pattern and are ubiquitous to the study area. All other trends are submaxima of one of the dominant trends and do not occur in all areas. Trends 4 and 6 form a conjugate pair about trend 5. Trend 1 is restricted to the east-central portion of the SMB and is related to northeast shearing within the East Dalhousie Fault Zone. Quartz veins and some dyke orientations parallel Trend 5 joints. Trends 3 to 6 are interpreted as resulting from northwest horizontal compression during synmagmatic deformation.

Mineralization within the SMB is strongly controlled by the regional fracture patterns. Uranium mineralization is generally associated with hematized Trend 3 joints while polymetallic vein-greisen mineralization is associated with Trend 5 joints.

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AL-RICH PYROXENES IN GRANULITE XENOLITHS FROM TANGIER: IMPLICATIONS TO LOWER CONTINENTAL CRUST, EASTERN MEGUMA ZONE, NOVA SCOTIA¹

A. K. Chatterjee and P. S. Giles

A wide assortment of rounded to angular xenoliths ranging in size from <1 cm to >100 cm occur in a post-Acadian NNW-trending spessartite dyke at Tangier. These xenoliths may be assigned to two groups: (A) graphite- and garnet-bearing and (B) devoid of these minerals. Group A xenoliths containing orthopyroxene (opx) have abundant spinel and aluminosilicates. Those containing clinopyroxene (cpx) have Al-rich sphene, apatite and amphibole. Other minerals common in Group A include quartz, sapphirine, mesoperthite, corundum, plagioclase, rutile, biotite, chlorite and muscovite. Mg values ($100 \text{ Mg}/\text{Mg}+\text{Fe}^{+2}+\text{Fe}^{+3}+\text{Mn}$) for Group A opx range from 32-74 and total Al (on the basis of 4 cations) in opx ranges from 0.10 to >0.80. Clinopyroxenes from Group A xenoliths are of diopside to salite composition, with total Al ranging from 0.05-0.15.

Xenoliths of Group B include 2-pyroxene granulites and opx-amphibole and cpx-amphibole granulites. Other mineral phases are quartz, K-feldspar, plagioclase, phlogopite, calcite, chlorite and sphene. Mg values for Group B opx range from 84 to 88 and total Al in opx ranges from 0.10-0.20. Clinopyroxenes in Group B xenoliths are exclusively of endiopside composition, with total Al ranging from 0.20-0.40.

Assessment of pyroxene composition in terms of components such as $\text{Ca}:\text{Mg}:\text{Fe}+\text{Mn}$ and $\text{Al}^{\text{IV}}-\text{Al}^{\text{VI}}$ reveals that Tangier dyke pyroxenes: (1) are atypical of those found in igneous rocks of various affinities, (2) are markedly different from those found in regional granulite terrains ranging in age from Archean to Hercynian and (3) are vastly different from pyroxenes of mantle origin. Furthermore, peak temperature (1030-1166°C) and pressure (14.2-14.8 kb) estimates are unlike those reported from regionally metamorphosed granulite terrains and suggest that the Tangier pyroxenes are indicative of lower crustal origin.

We consider it unlikely that doubly thickened crust

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could provide a mechanism to explain these P-T conditions and propose, alternatively, that heating of a single crustal plate through mantle magmatism could provide a more appropriate explanation. Links have recently been established between mafic plutonism, of which the Tangier dyke is a local manifestation, and "Acadian" granitoid plutonism with associated diapiric emplacement of high grade gneissic rocks (e.g. Liscomb Complex). These links in space and time suggest application of this model to a significant portion of the lower crust beneath the Meguma Zone.

THE TOBEATIC FAULT ZONE - POST-UISEAN SINISTRAL FAULT MOVEMENT IN SOUTHERN NOVA SCOTIA¹

P. S. Giles and A. K. Chatterjee

The Tobeatic Fault Zone (TFZ) comprises a zone of shear extending from the Wedgeport area of extreme southwestern Nova Scotia, northeasterly through the Vaughan-New Ross district where it cuts granitoid rocks of the South Mountain Batholith (SMB), to connect with post-Viscan fault systems defining the northern limits of the Shubenacadie Basin. Geological, geophysical and paleomagnetic evidence points to approximately 110 kilometres of post-Viscan sinistral displacement on the TFZ. With a strike length of up to 700 km including possible extension into the Gulf of Maine, the Tobeatic Fault Zone is of considerable significance to the understanding of the tectonic history of southern Nova Scotia.

Reconstruction realigns the Shubenacadie and Windsor Basins, creates an elliptical plutonic complex comprising the SMB, the Musquodoboit Batholith and the Liscomb Complex, and merges areas of Bouguer Gravity lows and radiometric highs in southern Nova Scotia. It also realigns Meguma slate belts of anomalous radio-element character.

The reconstruction juxtaposes and explains the close similarity of igneous rocks within the north-central SMB and the western Liscomb Complex. It also provides an important genetic rationalization for the distribution of many metallogenic domains of granophile character along the trace of the TFZ.

Stratigraphic evidence limits the movement history of the TFZ to post-Viscan time, whereas tenuous paleomagnetic data provide a younger limit of pre-Triassic. Fault deformation of the firmly dated Wedgeport Pluton documents movements younger than 315 Ma, i.e. Westphalian or younger.

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GEOCHEMISTRY OF THE LOWER CRUST BENEATH THE EASTERN MEGUMA ZONE, NOVA SCOTIA¹

G. W. Eberz², D. B. Clarke², A. K. Chatterjee and P. S. Giles

Xenoliths occurring in a spessartite dyke near Tangier (Nova Scotia) can be subdivided into two distinct mineralogical groups. Group A includes sapphirine-orthopyroxene and garnet-orthopyroxene granulites and most of them have abundant graphite, aluminosilicates and spinel. Group B xenoliths are devoid of graphite and aluminosilicates and include two-pyroxene, orthopyroxene-amphibole and clinopyroxene-amphibole assemblages. Both groups give peak P-T estimates of 12-14 kb and 1000-1100°C.

Group A xenoliths have high Al_2O_3 (x-22.5 wt. %) but variable SiO_2 (46-67 wt. %). They have an overall major element chemistry within the range of average shale but contrast sharply with Meguma Zone, low grade metasediments. Most Group A xenoliths are corundum-normative (3.5-18%), but some have normative diopside (aluminosilicate free) indicating a more calcareous protolith for the latter. Group B xenoliths have a narrow range in silica (50.46-51.31 wt. %) but a wide range in CaO (6.93-12.80 wt. %) and MgO (7.70-16.73 wt. %). Together with the high and variable compatible trace element abundances of Cr (x-923) and Ni (x-122) this reflects extensive crystal accumulation (cpx, opx, amph) of the igneous (basaltic) protolith. The K/Rb ratios for both groups (x-321) are similar to average Archean crust (approx. 300). Some trace element ratios, such as Th/U and Zr/Nb, are very similar for both groups, averaging 3.5 and 14 respectively. However, they can be clearly distinguished by their Ti/V and Ti/Zr ratios (Group A: $Ti/Zr < 40$, $Ti/V > 25$ and Group B: $Ti/Zr > 40$, $Ti/V < 25$).

Both groups show LREE enriched patterns but the total of 12 REEs is characteristically high for Group A xenoliths (106-248 ppm) when compared to Group B xenoliths (47-84 ppm). None of the REE patterns show positive Eu anomalies as is typical for the meta-tonalite-trondjemite-granodiorite suite of regional granulite terrains.

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The most remarkable feature of both xenolith groups is their high abundance of LIL elements, compared to rocks from other granulite facies terrains. This rules out significant melt extraction or loss of LIL elements during CO₂ flushing or prograde dehydration reactions. The lower crustal xenoliths are, therefore, unlikely source rock candidates for the Devonian-Carboniferous granitoids of Nova Scotia.

The data suggests the lower crust beneath the Meguma Zone is composed of shales, calcareous shales, mafic cumulates and gabbros.

PALEOENVIRONMENTS OF BURIED LATE-GLACIAL PEAT DEPOSITS IN NOVA SCOTIA¹

R. R. Stea and R. J. Mott²

Deglaciation is recorded in the Minas Basin region of Nova Scotia by the deltaic glaciofluvial and glaciomarine sediments of the Five Island Formation. Shell dates from bottomset beds of a delta at Spencers Island range from 14,300-12,600 yr. B.P. The Spencers Island delta records a prominent marginal stand marked by numerous deltas along the Minas Basin. The age of complete deglaciation of Nova Scotia is still unknown. The uncertainty is at least partially due to the evidence for a climatic oscillation at the end of the Late Wisconsinan. Peat beds were deposited between 12,700 yr. B.P. and 10,300 yr. B.P. They overlie glacial and fluvial deposits and are overlain by deposits of various origins. Pollen from these peat beds records the migration of spruce into the region, indicating climatic warming, and a subsequent deterioration of climate, recorded by the return of tundra-like flora. The peat beds are truncated by a variety of deposits including fluvial gravel and sand, lacustrine sand, silt and clay and till-like diamictos. Periglacial landforms and structures have been observed in these deposits at some sites. At Collins Pond, on the shore of Chedabucto Bay, a diamicton overlying the peat bed is characterized by strong fabrics parallel to the trend of other ice flow landforms in the region. The evidence suggests that at least some of these deposits are glacial, indicating that glaciers were active in Nova Scotia until 10,000 yr. B.P.

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THE SUCCESSION AND EXTENT OF WISCONSINAN ICE FLOWS IN NOVA SCOTIA, CANADA¹

R. R. Stea and D. R. Grant²

Recent Quaternary mapping in Nova Scotia has revealed a more complicated pattern of ice flows than predicted by previous Wisconsinan ice configuration models. Four ice flow phases have been recognized. The first ice flow (phase 1) crossed the Bay of Fundy and Nova Scotia in an eastward direction initially, then flowed southeastward and terminated offshore. The phase is believed to be Early Wisconsinan in age because: (1) a till formed during this glaciation is found directly above interglacial organic horizons dated at >50,000 yr B.P. and an emerged wave-cut bench assumed to be Sangamon in age; (2) extensive sand and clay beds have been found above the phase 1 till and below younger tills; (3) at Salmon River, a marine bed lying above a till formed during phase 1 has been dated Mid-Wisconsinan in age. The next ice flow (phase 2) radiated from a centre north of the Northumberland Strait. This glacier crossed the mainland in a southwest to southeast direction and terminated offshore. The southward ice flow was succeeded by flow from a divide which straddled the axis of the Nova Scotia peninsula and lay south of Cape Breton Island (phase 3). The last major event (phase 4) is recorded by till and striations formed during the activity of several small ice caps remnant after the Scotian Ice Divide. Soil data from terrain glaciated only during phases 1 and 2 implies that phases 2-4 are Late Wisconsinan in age.

Radiocarbon dates on glaciomarine deltas suggest that ice had cleared most of the Bay of Fundy at 14,300 yr B.P. Retreating ice after 14,300 yr B.P. left several ice margins on land defined by till boundaries and end moraines. There is growing evidence for remnant ice activity following a warm period from 11,500 - 10,500 yr B.P.

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GLACIAL DISPERSAL IN NOVA SCOTIA: AN AREA OF SHIFTING ICE DIVIDES¹

R. R. Stea, R. G. Turner, P. W. Finck and R. M. Graves

The glacial history of Nova Scotia is characterized by the interplay of external and local ice divides. A complex pattern of ice flows was imprinted on the landscape. Four major Wisconsinan ice flow events (phases 1-4) have been defined by mapping striations, interpreting till stratigraphy and provenance, and delineating the dispersal of distinctive rock types and ore bodies. The shape and magnitude of dispersal trains in Nova Scotia were largely controlled by the location and dynamics of regional and local ice sheets. The dynamics of these ice sheets controlled the erosion, entrainment and deposition of rock material. The migration of ice divides during the Wisconsinan Stage from external regions to local areas produced a series of zones, each defined by a distinct pattern of striations and dispersal.

The Meguma Terrane on the southern mainland is characterized by several zones related to the position of the Scotian Ice Divide responsible for northward flow during phase 3. The Scotian Ice Divide is located directly over the Meguma Terrane. Dispersal under the divide was largely southeastward and southward (flow phases 1 and 2). Areas south of the divide reveal broad dispersal fans trending southeast to southwest. In these zones locally-derived stony tills formed during phases 3 and 4 were deposited sporadically upon older tills.

Dispersal zones along the coast in the northern mainland reveal a different transport history. Near the New Brunswick border, three till units formed during phases 1, 2 and 4 record a change in source areas from west to northeast. The effect of northward ice flow from the Scotian Ice Divide (phase 3) becomes apparent along the Northumberland Strait and Georges Bay where superimposed till units show changes in source areas from west to southwest. Boulders from a

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hornblende diorite stock in northern mainland Nova Scotia were dispersed in lobes trending southeast, south, north and southwest.

EVENTS OF THE LATE WISCONSINAN-HOLOCENE TRANSITION IN NOVA SCOTIA¹

R. R. Stea and R. J. Mott²

Deglaciation is recorded in Nova Scotia by deltaic glaciofluvial and glaciomarine sediments. Shell dates on bottom-set beds of a delta at Spencers Island range from 14,300-12,600 yr B.P. The Spencers Island delta records a prominent ice marginal stand. A second ice margin was present on the lowlands north of the Minas Basin. It is marked by ice contact stratified drift, a series of lakes, pinch-out of a distinctive till sheet, and a terminal moraine in a valley a few km north of the Parrsboro outwash delta. The margin has not yet been directly dated, but the age is estimated to be between 12,500 yr B. P. and 10,000 yr B. P.

The age of complete deglaciation of Nova Scotia is still unknown. Peat beds were deposited during an interval, dated at 11,800 yr B.P. to 10,500 yr B.P. Pollen in these peat beds records the migration of spruce into the region indicating climatic warming, and a subsequent deterioration of climate recorded by the return of tundra-like flora. The peat beds are overlain by a variety of deposits including fluvial gravel and sand, lacustrine sand, silt and clay, and till-like diamictos. At Collins Pond, on the shore of Chedabucto Bay, a diamicton overlying the peat bed is characterized by strong fabrics parallel to the trend of ice flow landforms in the region. The evidence suggests that at least some of these deposits are glacial, indicating that glaciers were active in Nova Scotia until 10,000 yr B.P.

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INTRODUCTION TO TERRANE ANALYSIS¹

J. D. Keppie

Tectonostratigraphic terranes are defined as fault-bounded geological entities of regional extent, each characterized by a geological history that is different from the histories of contiguous terranes and cannot be explained by a facies change. The methodology of terrane identification varies with the depth of erosion and the degree of metamorphic and structural overprinting. Thus in unmetamorphosed to low grade units, the stratigraphic record is the main tool for terrane identification, and cratonic terranes may be separated by oceanic terranes. Considerable care must be exercised in correlating displaced parts of one terrane because a similar stratigraphic record may occur in distinct terranes. For example, separate oceanic basins occur between potential cratonic oceanic plateaux terranes, in the Pacific Ocean, Sea of Japan and the Indian Ocean. Also, cratonic terranes may have a similar geological record and still constitute separate terranes, e.g. potential cratonic oceanic plateaux in the Indian Ocean, or cratonic volcanic arc versus a remnant arc. On the other hand, in high grade regions, petrology, geochronology and structure may be the only available criteria, and cratonic terranes may be separated by a cryptic suture. In such high grade areas, distinguishing a cryptic suture from an intra-terrane fault/shear zone becomes critical. This is especially difficult where two similar cratonic terranes were formerly separated by oceanic terranes, the latter now represented by a cryptic suture.

An upper limit on the time of terrane accretion has generally been established by the age of overstepping sequences, stitching plutons, overthrusting, metamorphic overprinting and/or unique pebbles derived from one terrane and deposited on another. However, terrane boundaries often suffer a prolonged and complex history of movement following initial docking. Thus, these events may post-date the time of initial docking by a considerable time interval. Isotopic dating of metamorphic/structural fabrics associated with terrane accretion may more closely constrain the time of initial docking. Such fabrics may be preserved away from the overprinting fabrics adjacent to the terrane boundaries. A

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lower limit on terrane accretion may be provided by the age of the youngest rocks unique to adjacent terranes.

Kinematic analysis of the terrane boundaries may provide data on the mechanism of post-docking terrane accretion. However, predocking displacements rely on paleobiogeographic, paleomagnetic and environmental stratigraphic data. Tectonic interpretations of the tectonic elements in each terrane may be made by reference to neighbouring terranes only after docking. Prior to docking each tectonic element should be interpreted independently of its present neighbour. Such an analysis leads to a more objective plate tectonic interpretation.

NORTHERN APPALACHIAN TERRANES AND THEIR ACCRETIONARY HISTORY¹

J. D. Keppie

Recent geological mapping in the northern Appalachians has provided an improved data base for delineating terranes and providing better constraints on their accretionary history. A revised terrane map of the northern Appalachians is presented along with a series of diagrams outlining their accretionary history. The terranes may be grouped into the following categories from northwest to southeast:

(i) North American Terrane characterized on its eastern side by a Grenvillian basement overlain successively by a Late Precambrian-Ordovician miogeocline and an Ordovician foredeep;

(ii) terranes composed of continental rise and oceanic lithosphere thrust over the North American Terrane;

(iii) diverse terranes made up of volcanic arc complexes, oceanic lithosphere and microcontinents, which represent the vestiges of Iapetus;

(iv) diverse Precambrian terranes characterized by metamorphosed Helikian rocks, Hadrynian volcanic rocks of continental rift and cratonic volcanic arc complexes, many overlain by outliers of similar platformal Cambro-Ordovician rocks containing an Atlantic fauna which define the Avalon Composite Terrane;

(v) Meguma Terrane composed of Cambro-Ordovician turbidites overlain by Upper Ordovician-Lower Devonian rift volcanic rocks and shelf sediments containing a Rhenish fauna.

The accretionary history of these terranes may be broadly subdivided into the following sequence:

(a) Late Precambrian amalgamation of the Avalon Composite Terrane during the Cadomian Orogeny is constrained by the similarity of the Cambro-Ordovician outliers which are inferred to represent a formerly continuous overstep sequence;

(b) progressive oblique dextral convergence in the northwestern part of Iapetus between North America and a volcanic arc (Ascot-Weedon-Notre Dame) throughout the

¹ Paper presented at symposium on Tectonothermal Evolution of the West African Orogens and Circum-Atlantic Terrane Linkages, Nouakchott, Mauritania, December 1987

Ordovician culminated in continent-arc collision and accretion of intervening terranes;

(c) progressive oblique sinistral convergence in the southeastern part of Iapetus beneath a volcanic arc complex (Bronson Hill-La Poile) throughout the Ordovician, Silurian and early Devonian led to closure of Iapetus and amalgamation of intervening terranes and sinistral emplacement of the Avalon Composite Terrane along a deep vertical fault (Dover-Turtle Head Fault);

(d) progressive oblique dextral closure of the Theic Ocean between Avalonia and Gondwana led to accretion of Meguma Terrane by earliest Devonian and culminated in progressive continent-continent collision throughout the Devonian, Carboniferous and early Permian.

Reactivation of primary terrane boundaries during later deformational events has often obscured original accretionary constraints. Thus, overstep sequences, stitching plutons, accretionary fabrics and metamorphic overprinting may only provide upper limits on the reactivation rather than initial accretion.

AGE OF DETRITAL ZIRCONS AND SPHENE IN THE MEGUMA GROUP, SOUTHERN NOVA SCOTIA: CLUES FOR THE ORIGIN OF THE MEGUMA TERRANE¹

J. D. Keppie and T. E. Krogh²

Detrital zircons and sphenes from the Cambro-Ordovician turbidites of the Meguma Group in southern Nova Scotia have yielded U-Pb ages of circa 600 Ma (sphene and euhedral zircon needles), and discordant euhedral-rounded zircons falling on a chord intersecting concordia at circa 2.0 and 3.0 Ga. The 600 Ma zircons suffered almost no abrasion during sediment transport and are inferred to have come from an igneous source close to the source coast, while the 600 Ma sphenes could have come from either an igneous or a metamorphic source. The older zircons are inferred to have been derived from either a high grade metamorphic source or an igneous source 2.0 Ga old. If the source was metamorphic, then it could have been superimposed upon either igneous rocks with 3.0 Ga inheritance or sediments with a 3.0 Ga source. If the source was igneous, then it could have a 3.0 Ga inheritance. Thus, the 3.0 Ga source may or may not have been exposed as the source for the oldest zircons. Similar detrital zircons have been recovered from Cambro-Ordovician rocks in the European Hercynides. Source rocks may be found in the Baltic, West African and Guyana Shields, as well as in several basement blocks within the European Hercynides. The large size of the Meguma Group suggests the source was equally large and could favour one of the three shield areas. Of these, the Baltic Shield is least likely because it has a large belt of circa 1.0 Ga rocks across its southwestern side, and Late Proterozoic igneous rocks are generally absent. Available data do not allow the choice to be further restricted to the West African or Guyana Shields.

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METALLOTECTONIC MAPS: THE ECONOMIC POTENTIAL OF TERRANE ANALYSIS¹

J. D. Keppie

Metallogenic and metallotectonic maps attempt to relate mineral deposits to tectonic setting, initially within the framework of geosynclinal theory, but now replaced by plate tectonic theory. These maps are interpretive in contrast to the more factual mineral occurrence and metal province maps. In the same way, a tectonic map illustrates the evolution of the outer part of the Earth through time and is interpretive, whereas geological and structural maps are more factual. A Tectonic Element is defined as a specific, tectonic environment characterized by a distinct tectono-stratigraphic or tectono-plutonic rock unit. A metallotect is defined as a genetically related group of metals which is cogenetic with a Tectonic Element. Tectonic Elements and Metallotects may be grouped into several Tectonic Stages, e.g.:

STAGE	METALLOTECT	TECTONIC ELEMENT
Stable	stratabound Fe-Mn conglomerate U-Au	in epicontinental basin in intracontinental basin
Collision	Sn-W-U-F-Mo-Au pegmatitic Nb-Ta Au-Zn-Mn veins sandstone U-Cu-V	in collision plutons in collision plutons in collision structures in foreland, hinterland and
	stratabound Pb-Zn-Cu U-Fe-Th-REE-Sr-Ba	in intramontane basins in alkalic volcanic rift
Subduction	alluvial Au-Sn	in retroarc compressive basin
	Au-Hg-F-Sb volcanics	in retroarc extensional basin
	P black shale	in backarc basin
	Cu-Fe-Zn basalts	in backarc basin
	Cr ultramafics	in backarc upper mantle
	Besshi-type Cu-Zn	in backarc basin seamount
	Hg-Au-Te andesites	in volcanic arc
	Sb-W-Hg basalts	in volcanic arc
	Fe-apatite rhyolites	in volcanic arc
	Kuroko-type Zn-Pb-Cu	in volcanic arc rift
	Cu-Au-Mo porphyry	in magmatic arc

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	placer Au	in	forearc basin
	Hg-Sb-W flysch	in	forearc basin
	Au veins	in	trench complex
Spreading	Mn-Ni-Co nodules	in	oceanic crust layer 1
	Cu-Fe-Zn basalts	in	ocean crust layer 2
	Cu-Ti gabbro	in	ocean crust layer 3
	Ni-Cr-Pt ultramafics	in	upper mantle
	Cyprus-type Cu-Fe-Zn	in	ocean transform
	placer Ti-Zr	in	continental shelf
	Pb-Zn carbonates	in	continental shelf
	banded iron formation	in	continental shelf
Rift	Cu-U-REE carbonatite	in	within-plate pluton
	alkaline U-Sn-Nb	in	within-plate pluton
	sandstone U	in	rift valley
	Sullivan Ag-Pb-Zn	in	rift valley

IMAGE PROCESSING APPLIED TO REGIONAL GEOCHEMICAL DATA FOR MINERAL EXPLORATION¹

G. F. Bonham-Carter², P. J. Rogers and D. J. Ellwood²

Making digital images of regional geochemical survey data is useful because such images can be displayed and analyzed to show anomalies, spatial trends and correlations with other images. However, regional survey values are point samples from a complex geochemical surface, and interpolation around sample points is associated with a great deal of uncertainty. This can readily be demonstrated using variograms, which show the spatial autocorrelation present in the data.

As an alternative to interpolation, geochemical data can be shown as themes which fill polygons, each polygon being associated with a sample site. For lithogeochemical and soil geochemical data, circular polygons centred on the sample site, or Voronoi tessellations, may be suitable. For stream and lake data, catchment basin polygons are most appropriate.

Polygons can be linked to a table of attributes, comprising geochemical analyses for one or more elements. Displays of single (or multiple) attributes are achieved by filling polygons from a colour or black/white palette. Integration of geochemical data with other images is carried out using the geochemical polygons to 'sample' other images. For example, the geological composition of a polygon may be characterized using the areal proportions of map units occurring within it. The radiometric composition of a polygon can be likewise characterized by determining the mean and variance of the radioelement values occurring along those parts of the flight lines enclosed by the polygon. The elevation, steepness and orientation of the ground area enclosed by the polygon can be measured from digital elevation data.

Polygons can be associated with derived attributes, such as principal component scores, predicted and residual values, or selected multi-attribute anomaly values. When combined with digitized vector data, such as streams, geological contacts, and faults, the potential for producing valuable

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interpretative images, or customized maps at any scale in hard copy, becomes enormous.

Digital maps made from a vector-raster spatial data system are shown for the Cobequid Highlands, Nova Scotia.

GOLD IN MEGUMA ZONE LAKES¹

P. J. Rogers

Chemical analyses for Au from lake sediments within the Meguma Zone of southern Nova Scotia show areas with anomalous Au values. Some of these anomalous geochemical patterns are related to known Au deposits within Meguma Group sediments. Other anomalous areas remain unexplained and study of their lake sediment geochemistry indicates new areas for Au exploration within the Meguma Zone.

Interpretation of lake sediment geochemistry is best considered using the lake catchment basin as the area of influence for the geochemical sample. Gyttja, the sample medium, is representative of the geological composition of the lakes' catchment basin and represents an efficient and cost-effective geochemical exploration indicator for Au. Lake bottom sediments themselves are the end-product of a complex geochemical system and these sediments act as geochemical sinks trapping a mixture of chemical and mechanical weathering components within the lake bottom (gyttja) layer.

The use of analytical methods for Au and their precision and reproducibility is illustrated by data from the Halifax Peninsula. The use of Neutron Activation Analysis and other analytical packages for Au is only warranted when sufficient sample is available. For Au analysis a minimum sample size of 10 g is recommended.

The Au geochemical pattern in the Meguma Zone lake sediments produces at first a puzzling mixture of responses at the 1:500 000 scale. Known Au districts in the Meguma Zone, such as Fifteen Mile Stream, have a positive geochemical response at the regional (1:500 000) and local (1:50 000) scale with highs of up to 853 ppb. After removal of the explained geochemical responses, a residual, unexplained dataset remains. This recontoured dataset, with the assumed effects from known Au deposits removed, indicates new exploration targets for the Meguma Zone granitic batholiths. Some of these new target areas in the Musquodoboit and South Mountain Batholiths will be presented for discussion.

¹ Presented at the Gold Exploration Workshop, Nova Scotia Department of Mines and Energy, March 1987

INTEGRATED MINERAL EXPLORATION USING CATCHMENT BASIN ANALYSIS, COBEQUID HIGHLANDS, NOVA SCOTIA¹

P. J. Rogers, G. F. Bonham-Carter² and D. J. Ellwood²

A pilot study previously reported in Bonham-Carter et al. (1987) and Rogers et al. (1986) discussed the application of catchment basin analysis to the integration of surficial geochemistry with bedrock geology using image analysis. This paper reports on an extension of this work to (a) cover a larger area, (b) further refine the method for characterizing geochemical background for the regional survey and (c) include a measure of variability based on field duplicates.

The Cobequid Highlands of northern Nova Scotia comprise an elongated area 160 km east-west by 50 km north-south, rising to a maximum of 350 m above sea level. A central core of Precambrian and Lower Paleozoic schists, gneisses, volcanics and sediments is intruded by numerous Devonian-Carboniferous granitoids. The highlands are bounded to the south by the major Cobequid - Chedabucto Bay fault system and to the north by the Cumberland Basin. The flanking lowlands comprise Late Paleozoic to Mesozoic rocks. Known mineralization has been identified in various significant associations, including Cu-U sandstone-hosted deposits, fault-related Mn deposits, poorly understood vein deposits containing precious metals, and polymetallic vein deposits. Mapping at 1:50 000 scale has identified about 65 rock units. This bedrock map has been raster scanned and the resulting digital image is 3335 x 960 pixels (50 m/pixel).

A 1983 regional stream-sediment geochemical survey collected about 1500 -80 mesh samples, at an average density of 1 sample per 2.5 km². These samples were analyzed for Cu, Pb, Zn, Ag, Fe, Mn, Ni, Co, As, Hg, U and Mo in sediments, U, F and pH in surface waters. Field duplicates were collected at 1 site in 20. One of each duplicate pair was split to act as the analytical control.

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Sample locations were plotted on a 1:50 000 scale base topographic map and catchment basins upstream from each site outlined by hand. The resulting map was also raster scanned to produce a second image in registration with the geological base. A computer file describing the geochemical composition of each sample and the geological composition (map units) of its associated catchment basin was created. Field sampling strategy included some nested basins, so samples are not necessarily geochemically or statistically independent from one another.

Coloured maps from an Applicon ink jet plotter using a percentile scale were made for each element. Each catchment basin was coloured according to the sample value, instead of using symbol plots or interpolation schemes which normally assume that the area of influence is centred on the sample location.

These plots reveal broad trends to major structural features and stratigraphic units. The first three principal components of the logarithms of the element data (explaining 64% of variance), plotted as factor scores with each factor as one of three primary colours, reveal a number of distinct geochemical provinces. These geochemical provinces are of distinct geological composition, and the plots provide a valuable summary of background geochemistry and its relationship to geology and structure.

The relationship between element concentration and its variance has been modelled using the field duplicates. This permits estimation of 95% confidence limits for cutoff values between colour classes, for untransformed single element plots.

Regression analysis has been used to model background effects for each element using areal proportions of mapped units as independent variables. After removing background, residual maps enhance the definition of anomalous areas and aid in target selection for exploration. Tables showing average background response for each unit are produced.

Catchment basin plots not only provide an insight into the spatial variation of multi-element associations and their geological control, but also isolate potential exploration targets which can then be integrated with other data sources, such as remotely-sensed radar and airborne geophysics. The ultimate goal of this integration study is to produce target area maps based on ore deposit models.

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THE GEOLOGICAL HIGHWAY MAP OF NOVA SCOTIA: A SECOND EDITION¹

H. V. Donohoe, Jr. and R. Grantham²

Eight years ago the Atlantic Geoscience Society published the Geological Highway Map of Nova Scotia for the 1980 GAC/MAC Halifax meeting. The press run was 16,000 maps; now less than 2,000 remain. The map has been used by visitors, residents, geologists, students and teachers. In many schools and some university courses it is part of the curriculum. With the low number of maps remaining and the many advances in the geological understanding of Nova Scotia, another edition was needed. In early 1987 an AGS committee was formed to begin preparation of another edition. The committee has a broad base of experience with its members: Howard Donohoe (N.S. Mines and Energy); Robert Grantham (N.S. Museum); Gordon Fader (Atlantic Geoscience Centre); John Martell (Dartmouth High School); and Robert Raeside (Acadia University). This second edition of the map will be more "user friendly" than the preceding one. On the front, the geological map will be correctly oriented geographically and will have the same increased size as the newer edition of the Nova Scotia Tourism Highway Map. We will be working toward integrating relief and geology on the map so that users will understand how the geology of an area has affected the landscape. Block diagrams will be used both on the front in place of cross-sections and on the back for discussion of local areas. Other novel ideas for stronger and more graphic presentations of geology and landforms are being discussed. These include "exploded" views of an area using a layered effect: the bedrock layer, surficial deposits layer and surface cultural features and landforms layer. Mining and the mineral industry in Nova Scotia will be emphasized through panels on the back and locations of mines on the front map. We feel that the new edition of the map will be able to show users more about the geological history, mineral resources, rocks and fossils and landform development with less complication and fewer words.

¹ Paper presented at the Atlantic Geoscience Society Symposium, Antigonish, Nova Scotia, February 5-7, 1988

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MOVEMENT HISTORY OF THE COBEQUID FAULT ZONE, COBEQUID HIGHLANDS, NORTHERN NOVA SCOTIA¹

H. V. Donohoe, Jr., and P. I. Wallace²

The Cobequid Fault Zone (CFZ) is a complex linear feature defined by numerous, generally E-W faults that cross Northern Nova Scotia between Cape Chignecto and northeast of Truro. In this sense the Cobequid Highlands massif, which is bounded, broken and cut by the E-W faults, is part of this large fault zone. The CFZ is the Carboniferous and Mesozoic manifestation of movement between the Avalon Composite Terrane and the Meguma Terrane that began in Devonian or earlier time as the Minas Geofracture. From the Late Devonian to the Late Carboniferous, movement on the CFZ: 1) deformed rocks in some fault blocks, 2) isolated rock units, 3) influenced sedimentation, 4) facilitated the extrusion of three to six kilometres of bi-modal volcanic rocks (Fountain Lake Group) and 5) acted as a locus for Devonian and Carboniferous plutonism. Sedimentation was episodic and mainly influenced by relative vertical movements on the CFZ. The Fountain Lake volcanics are found across the Highlands in fault controlled outcrops. Flow directions and slices of volcanic rock in the CFZ indicate that the volcanic rocks covered much of the area south of the Highlands. Emplacement of plutons was part of an intrusive process in shear zones analogous to examples in the South Armorican Shear Zone of Brittany. The transcurrent movement was episodic and appears to be mainly confined to the Early Carboniferous, although additional movements took place during Late Carboniferous and Triassic-Jurassic times, coupled with vertical movement. The result of the Namurian movement was the isolation and deformation of a large block of (?) Early Carboniferous siltstone/wacke (Greville River Formation) and smaller blocks of Fountain Lake Group rhyolites, Hadrynian aged Jeffers Group mafic volcanics and Windsor Group limestones and sediments. The mylonitization and truncation of several Early Carboniferous aged plutons by active faults and the subsequent emplacement and deformation of the Pleasant Hills Pluton dates this episode of transcurrent movement at c. 330 Ma. The estimated composite horizontal movement is 80 to 120 km minimum for Namurian time; younger movements are not as well documented. By Westphalian A time most of the faults

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along the northern side of the CFZ had been overstepped by sedimentation and movement was concentrated on the southern side of the Cobequid Highlands. Continued horizontal motion on the CFZ during the latter part of the Carboniferous has complexly deformed the middle Carboniferous aged Cape Chignecto Pluton. At this location the CFZ changes its orientation from E-W to WSW; what was mostly horizontal movement on the E-W CFZ became more transpressive with the accompanying development of thrusts and low angle shear zones. The Pluton has large areas with near horizontal mylonites that are not found elsewhere in the same aged rocks. This episode began in (?) Westphalian time and continued until the cessation of thrusting in the Saint John, New Brunswick region (late Westphalian). The southern part of the CFZ, mainly south of the Highlands, became active again during rifting in Middle Triassic time. Dip-slip movement continued intermittently between Triassic and Early Jurassic time along the locus of the Minas Geofracture. Some horizontal motion appears to have deformed Late Triassic sediments along the Cobequid Fault. The CFZ was an active boundary between the two terranes for a long period of time and represents an impressive record of movement.

SEDIMENTATION, TECTONICS AND CARBONIFEROUS BASIN EVOLUTION ADJACENT TO THE COBEQUID HIGHLANDS MASSIF, NORTHERN NOVA SCOTIA¹

R. J. Ryan, H. V. Donohoe and R. C. Boehner

The Cumberland Basin and the northern part of the Minas Basin constitute part of the Maritimes Basin, the erosional remnant of a large Carboniferous Basin which covered much of Atlantic Canada. The Maritimes Basin is interpreted as a series of interrelated basins (horsts and basins?) which at various times underwent differing rates of subsidence and uplift. The Carboniferous strata adjacent to the Cobequid Highlands Massif comprise three packages which are interpreted to reflect major tectonic events with possible paleoclimatic influences. The three sedimentary allocycles are: (1) the Upper Devonian to Lower Namurian, Fountain Lake Group to Lower Canso Group; (2) the Upper Namurian to Westphalian A, Upper Canso Group and Riversdale Group; and (3) the Westphalian B to Lower Permian, Cumberland and Pictou Groups. Each of the allocycles record an initial rapid basin subsidence and/or highland uplift, followed by a decelerating subsidence rate. The initial rapid subsidence (and/or uplift) resulted in deposition of fanglomerates at the basin margins which are succeeded by a transition to fluvial, lacustrine, and in one case a marine basin fill. The later episodes of the basin infilling are recorded by laterally extensive blanket-like units which overstep the basin margins onto the basement rocks. The allocycles are interpreted as alternating periods of (1) strike-slip related subsidence in tilted fault wedge basins (sub-basins) and (2) regional flexural subsidence occurring throughout the basin. This three cycle sequence does not appear to be consistent with a single pull-apart and subsequent thermal subsidence model proposed by various workers for the Maritimes Basin. Carboniferous age wrenching along the suture zone between the Meguma Terrane and the Avalon Terrane was probably the driving force which resulted in the development of the allocycles within the adjacent basins.

¹ Paper presented at the Atlantic Geoscience Society Symposium, Antigonish, Nova Scotia, February 5-7, 1988

PETROGRAPHY AND GEOCHEMISTRY OF ANHYDRITE FROM THE PUGWASH SALT MINE, PUGWASH, NOVA SCOTIA¹

P. A. Rose² and D. C. Carter

Evaporites exposed in the workings of the Canadian Salt Co. mine at Pugwash, Nova Scotia, have been the subject of a number of studies, but only limited petrographic and geochemical work has been done on anhydrite from the deposit. Based on internal characteristics observed in both the mine workings and drill core, three anhydrite units are recognized macroscopically and have been informally termed the shaft, borate and third anhydrites.

The shaft anhydrite is characterized by the following textures: (1) microcrystalline, associated with minor blocky, felted, aligned-felted and lath shaped crystals; (2) nodular, showing displacive growth within carbonate and dolomite laminae; and (3) laminated, with alternations of carbonate and anhydrite. The shaft anhydrite has dark organic-rich laminae crosscut by veinlets filled with coarse, crystalline anhydrite.

The borate anhydrite exhibits three separate habits that do not show intimate association as in the shaft anhydrite. The habits are: (1) microcrystalline, (2) felted and (3) aligned-felted. Peculiar to the borate anhydrite is the arrangement of coarse, ragged laths of anhydrite in fibroradiate groups. The presence of small, round, opaque aggregates of danburite crystals is unique to this unit.

The third anhydrite is texturally similar to the borate anhydrite, exhibiting felted and aligned-felted textures. However, the third anhydrite does not contain borate nodules and possesses more consistent and well defined alignment of anhydrite laths within aligned-felted portions. The highly ordered alignment of anhydrite laths in this unit is very distinctive and has not been observed in the other two anhydrites. In contrast to the shaft and borate anhydrite units, where nodules are invariably surrounded by carbonate,

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nodular mosaic portions of the third anhydrite contain micro-crystalline nodules surrounded or rimmed by aligned-felted anhydrite crystals.

Statistical analysis of geochemical data shows that each unit exhibits distinct chemical characteristics. The shaft anhydrite is the most inhomogeneous, contains the highest concentrations of several trace and minor elements and has the highest carbonate content. The third anhydrite is the most homogeneous, with low concentrations of almost all elements and the highest gypsum content. The borate anhydrite is intermediate in composition but has the highest halite content.

CAPROCK AND STRATABOUND BIOEPIGENIC SULPHUR IN NOVA SCOTIA¹

D. C. Carter, R. C. Boehner and G. C. Adams

Worldwide, all commercially important deposits of native sulphur originated as bioepigenic replacements of gypsum or anhydrite. Native sulphur deposits occur in two distinct geological settings: (1) caprock deposits overlying salt diapirs and (2) stratabound deposits within evaporite sequences.

Two occurrences of native sulphur have been documented from mainland Nova Scotia: (1) from the underground workings of the Canadian Salt Company at Pugwash, Cumberland County, and (2) from exploration drilling near Hilden, Colchester County. The Pugwash occurrence has characteristics in common with salt dome, caprock deposits in southeast Texas and Louisiana. The Hilden occurrence is similar to the stratabound deposits of western Texas and northern Iraq. Bioepigenic sulphur deposits are associated with dominantly marine evaporite sequences in sedimentary basins where structural controls have supplied extensive plumbing to allow for long-term mixing and flushing of artesian meteoric water through hydrocarbon-bearing strata and the evaporite deposit. Flushing promotes the growth of sulphate-reducing bacteria, which obtain energy through the oxidation of hydrocarbons.

These occurrences indicate that, at least on a limited scale, conditions necessary for the formation of bioepigenic native sulphur existed within the Windsor Group evaporite sequence of Nova Scotia. Detailed exploration and evaluation will determine the resource potential.

¹ Paper presented at the Atlantic Geoscience Society Symposium, Antigonish, Nova Scotia, February 3-7, 1988

THE MARITIMES BASIN: BASIN, EPIEUGEOSYNCLINE, TAPHROGEOSYNCLINE, HORST-GRABEN, WRENCH, RIFT, SUCCESSOR, AULACOGEN, PULL-APART, TRANSPRESSION? -BASINS, SUBBASINS? -JUST A PROBLEM OF SEMANTICS?¹

R. C. Boehner, R. J. Ryan and D. C. Carter

Upper Paleozoic rocks in Atlantic Canada have been described and interpreted in a rapidly evolving series of sedimentological and tectonic models over the past 60 years. This has resulted, especially in the past 20 years, in the proliferation of a complex terminology of geological-geographical basin and subbasin names as well as genetic names based on sedimentological and tectonic-structural models. The confusion in terminology (particularly for nongenetic application) arises from several factors: (1) vague definition and intent, (2) subsequent minor to radical redefinition or adaptation, (3) conflicting interpretations of constituent features both spatially and genetically, (4) mixed terminology, (5) rapid evolution in tectonic models and (6) excessive generalization. Any solution to the problem involves the co-operative establishment of a coherent, adaptable and flexible system of nomenclature. The nomenclature could be organized into two independent systems based upon application and with appropriate definitions and guidelines: (1) a nongenetic nomenclature (with geographic name priority) describing present-day features without genetic implications, to be used for general reference typically in a nongenetic sense; (2) a genetic nomenclature (independent of the above) applied to interpretive features based upon tectonic, structural, sedimentological and geophysical models. To eliminate mixing of genetic and nongenetic terms, features formally named in the two systems may not have the same geographic identifier. The name Maritimes Basin, as introduced by Roliff (1962), is proposed as a nongenetic general term applicable in the geographic sense to all upper Paleozoic rocks in Atlantic Canada. Consideration and discussion by interested workers of outstanding problems in name corruption, definition and hierarchy, as well as options for possible solution will be important in reconciling the present situation.

¹ Paper presented at the Atlantic Geoscience Society Symposium, Antigonish, Nova Scotia, February 5-7, 1988

CUMBERLAND BASIN STRATIGRAPHY: THE CLASSIC JOGGINS SECTION OF LOGAN AND FLETCHER, AND WINDSOR GROUP CORRELATION¹

R. J. Ryan and R. C. Boehner

The Joggins shore section is located in the western part of the Cumberland Basin. It contains a superb, almost completely exposed cross-section through parts of the Minudie Anticline and the Athol Syncline extending 55 km from Mill Cove (Minudie) in the north to Squally Point in the south. The section is made up of over 5000 m of gently-dipping strata, ranging in age from Visean to Westphalian D, which are only locally disturbed by faults. Rocks of the Canso, Riversdale and Cumberland Groups are well exposed in cliffs and wavecut platforms along the shore. The Canso Group strata can be divided into the red sandstones and siltstones of the Middleborough Formation and the grey sandstones and red shales of the Shepody Formation. The Riversdale Group is represented by the conglomeratic Claremont Formation and the overlying grey sandstone-dominated Boss Point Formation. The Boss Point Formation may in turn be subdivided into the Dogfish Reef, Boss Quarry, Bacon Ledge and North Reef Members based on sand/silt ratios. The Cumberland Group is divided into the Joggins, Springhill, Ragged Reef and the Malagash Formations. The Joggins Formation and the Springhill Formation constitute the fine grained strata that contain exploitable coal resources. The Ragged Reef Formation, although coal-bearing, is dominated by pebbly sandstones and fine conglomerates with only thin shale and coal interbeds. The Malagash Formation also contains significant coal beds, however it can be distinguished from other strata by the predominance of red coloration and age. Although not present in outcrop at Mill Cove, the Windsor Group (B Subzone) section is dominated by redbeds with at least three distinct marine carbonate units. These units are recognized and correlatable in outcrop over 60 km from Pugwash across the basin to Minudie. Younger Windsor Group carbonate members are apparently not widespread in the Cumberland Basin due to nondeposition or erosion. The carbonates may be facies equivalent to continental redbeds analogous to equivalent

¹ Paper presented at the Atlantic Geoscience Society Symposium, Antigonish, Nova Scotia, February 5-7, 1988

rocks in southern New Brunswick where marine carbonates are rare and the section is dominated by continental redbeds.

APPENDIX I
GEOLOGICAL SURVEY OF CANADA
CANADA - NOVA SCOTIA MINERAL DEVELOPMENT AGREEMENT PROJECTS



The following reports have been published in Current Research, Part B, Geological Survey of Canada, Paper 88-1B, 299 p. (1988) and are products of the Canada - Nova Scotia Mineral Development Agreement.

Graves, M. C. and Zentilli, M.

The lithogeochemistry of metal-enriched cotecules in the Goldenville - Halifax transition zone of the Meguma Group, Nova Scotia, p. 251-262.

Hamblin, A. P.

A preliminary report on the sedimentology, tectonic control and resource potential of the Upper Devonian-Lower Carboniferous Horton Group, Cape Breton Island, p. 17-22.

Hill, J. R.

Geochemical differentiation of Precambrian metacarbonate assemblages, Cape Breton Island, Nova Scotia, p. 173-186.

Murphy, J. B., Pe-Piper, G., Nance, R. D. and Turner, D.

A preliminary report on geology of the eastern Cobequid Highlands, Nova Scotia, p. 99-108.

Nance, R. D. and Murphy, J. B.

Preliminary kinematic analysis of the Bass River Complex, Cobequid Highlands, Nova Scotia, p. 227-234.

Tallman, P., Sangster, A. and Jamieson, R. A.

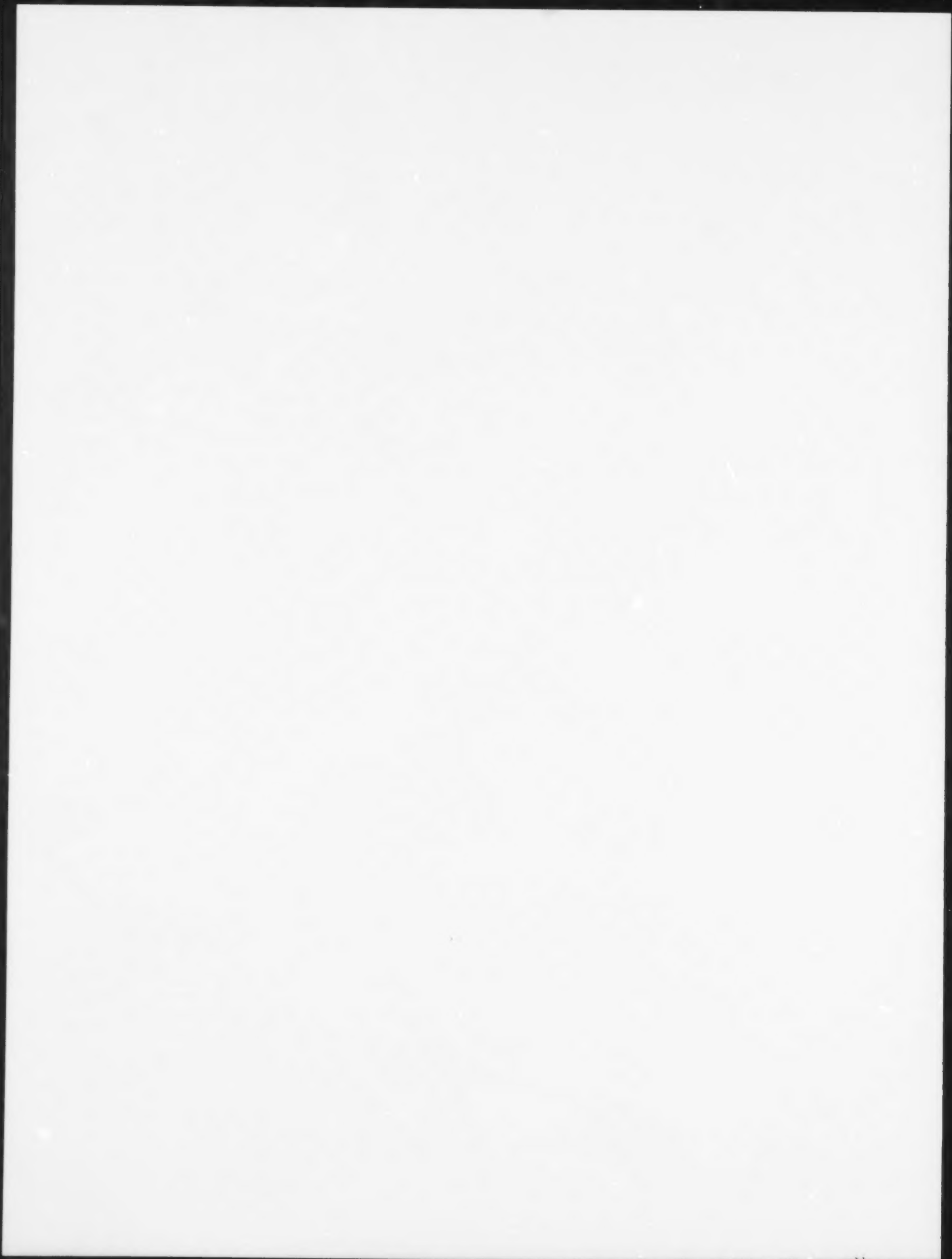
Geology and mineralization of the Jumping Brook metamorphic suite, Faribault Brook area, western Cape Breton Island, Nova Scotia, p. 108-118.

Yeo, G. M., Kalkreuth, W. D., Dolby, G. and White, J. C.

Preliminary report on petrographic, palynological, and geochemical studies of coals from the Pictou Coalfield, Nova Scotia.



APPENDIX II
NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY
PUBLICATIONS AND MAPS
AVAILABLE FOR PURCHASE



PAPERS

- Paper 76-1 Structural Model for the Saddle Reef and Associated Veins in the Meguma Group, Nova Scotia, by J. D. Keppie, 34 pages, 2 maps. (\$3.00)
- Paper 76-2 Geological Data Collection in the Nova Scotia Department of Mines, by J. D. Keppie and A. K. Chatterjee, 15 pages. (\$0.50)
- Paper 76-3 Interpretation of P.P.I. Radar Imagery of Nova Scotia, by J. D. Keppie, 31 pages, 1 map. (\$1.25)
- Paper 76-4 Geology, Geochemistry and Mineral Occurrences of the Northeast Margaree River Drainage Basin in parts of Inverness and Victoria Counties, Cape Breton, Nova Scotia, by B. E. MacNabb, J. H. Fowler and T. G. N. Covert, 30 pages, 12 maps. (\$15.00)
- Paper 76-5 Guide to the Invertebrate Fauna of the Windsor Group in Atlantic Canada, by R. G. Moore and R. J. Ryan, 57 pages. (\$2.25)
- Paper 77-1 Tectonics of Southern Nova Scotia, by J. D. Keppie, 34 pages (Reprinted 1980). (\$3.00)
- Paper 77-3 Plate Tectonic Interpretation of Paleozoic World Maps (with Emphasis on Circum-Atlantic Orogens and Southern Nova Scotia), by J. D. Keppie, 45 pages (Reprinted 1982). (\$4.00) (Microfiche \$1.50)
- Paper 77-6 Sand and Gravel Resources of Pictou County, by J. H. Fowler and G. B. Dickie, 42 pages, 1 map. (\$4.00)
- Paper 77-7 Tungsten Mineralization in the Carbonate Rocks of the George River Group, Cape Breton Island, Nova Scotia, by A. K. Chatterjee, 26 pages. (\$3.50)
- Paper 78-1 Geology of the Ecum Secum Area, Halifax and Guysborough Counties, Nova Scotia, by D. McBride, 12 pages. (\$1.00)
- Paper 78-2 Age of Igneous Rocks along the Lennox Passage - St. Peter's Lineament, Southern Cape Breton Islands, by J. D. Keppie and P. K. Smith, 10 pages. (\$1.00)
- Paper 78-3 Geology of the Giant Lake Area, Southeastern Cape Breton Island, Nova Scotia, by P. K. Smith, 30 pages, 1 map. (\$2.00)
- Paper 78-4 Some Middle Devonian to Lower Carboniferous Rocks of Cape George, Nova Scotia, by J. D. Keppie, P. S. Giles, and R. C. Boehner, 37 pages. (\$2.00)
- Paper 78-5 Petrology of the Early Silurian Dunn Point and McGillivray Brook Formations, Arisaig, Nova Scotia, by J. D. Keppie, J. Dostal and M. Zentilli, 20 pages. (\$1.00)
- Paper 79-1 Petrology of the Late Precambrian Fourchu Group in the Louisbourg Area, Cape Breton Island, by J. D. Keppie, J. Dostal and

- J. B. Murphy, 18 pages.
(\$1.50)
- Paper 79-2 Opencast Coal Reserves at Springhill, by B. Ward, 40 pages, 4 maps. (\$4.50)
- Paper 79-3 Geology of the Meat Cove Zinc Deposit, Cape Breton Island, by A. K. Chatterjee, 27 pages. (\$2.00)
- Paper 79-4 Minor and Trace Element Variations in Wisconsin Tills, Eastern Shore Region, Nova Scotia, by R. R. Stea and J. H. Fowler, 30 pages, 3 maps. (\$10.00)
- Paper 79-5 Pleistocene Stratigraphy of the Miller Creek Section, Hants County, Nova Scotia, by R. Stea and D. Hemsworth, 16 pages. (\$3.00)
- Paper 79-6 Effects of Subsidence and Depositional Environment on the Formation of Lithotypes in a Hypautochthonous Coal of the Pictou Coalfield, by J. H. Calder, 23 pages. (\$3.00)
- Paper 79-7 Carbonate Banks of the Gays River Formation in Central Nova Scotia, by P. S. Giles, R. C. Boehner and R. J. Ryan, 57 pages, 1 map. (\$4.00)
- Paper 80-1 Geology of the Cape North Area, Northern Cape Breton Island, Nova Scotia, by A. S. Macdonald and P. K. Smith, 60 pages, 2 maps. (\$5.00) (Microfiche \$2.00)
- Paper 81-1 The Fisset Brook Formation at Lowland Cove, Inverness County, Nova Scotia, by P. K. Smith and A. S. Macdonald, 18 pages. (\$2.00) (Microfiche \$1.00)
- Paper 81-2 Major Transgressive-Regressive Cycles in Middle to Late Visean Rocks of Nova Scotia, by P. S. Giles, 27 pages. (\$2.00) (Microfiche \$1.50)
- Paper 81-3 The Windsor Group of the Mahone Bay Area, Nova Scotia, by P. S. Giles, 51 pages, figure in back pocket. (\$4.00) (Microfiche \$1.50)
- Paper 81-4 Principles of Tectonic Mapping Based upon Plate Tectonic Theory, by J. D. Keppie, 11 pages. (\$1.50) (Microfiche \$1.00)
- Paper 82-1 Geology and Geochemistry of Selected Granitoid Plutons of Cape Breton Island, by S. M. Barr, G. A. O'Reilly and A. M. O'Beirne, 176 pages, 44 figures, 13 tables. (\$8.00) (Microfiche \$2.00)
- Paper 82-2 Metasomatic-Hydrothermal Mineral Deposits of the New Ross-Mahone Bay Area, Nova Scotia, by G. A. O'Reilly, E. J. Farley and M. H. Charest, 96 pages. (\$5.00) (Microfiche \$1.50)
- Paper 84-1 Petrology of Granitoid Rocks of the Boisdale Peninsula, Central Cape Breton Island, Nova Scotia, by S. M. Barr and J. R. D. Setter, 1986, 75 pages, includes Nova Scotia Department of Mines and Energy Map 84-2 folded in back pocket. (\$8.00) (Microfiche \$2.00)
- Paper 85-2 The formation of veins in

greenschist facies rocks and the early deformation of the Meguma Group, Eastern Nova Scotia, by B. H. O'Brien, 1985, 35 pages. (\$3.00) (Microfiche \$1.00)

Paper 86-1 Cretaceous Deposits of Nova Scotia, by G. B. Dickie, 1987, 54 pages. (\$15.00) (Microfiche \$3.00)

REPORTS

Report 75-1 Report of Activities of the Mineral Resources and Geological Services Division, 1974, by Nova Scotia Department of Mines, 75 pages. (\$1.00)

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Report 78-3 Superseded by Report 81-6.

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Report 79-2 Drilling Logs of Government Core Drills, 1978, by I. MacDougall and D. E. Polley, 54 pages. (\$2.00)

Report 80-1 Mineral Resources Division, Report of Activities, 1979, 248 pages. (\$7.00)

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- Report 81-7 Index to Drillhole and Well Data, 1862-1980, by N. A. Lyttle and J. Gillespie-Wood, 127 pages. (\$10.00) (Microfiche \$3.00)
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- Report 82-5 Keyword Index to GSC Documents on Nova Scotia to 1980. (Microfiche \$2.00)
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- Report 86-2 Index to Assessment Reports 1981-1985 (with Keyword and Map Indexes), by Norman A. Lyttle, Janet Gillespie-Wood, Gary M. Frotten and Mary Jean Fraser-MacKinnon, 178 pages. (\$20.00) (Microfiche \$8.00)
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Memoir 7 The Geology of the George River Series, Cape Breton, by G. C. Milligan, 1970, 111 pages, 7 maps. (\$4.50)

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pages, 5 maps. (\$2.00)

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Bulletin 2 Limestones and Dolomites of Nova Scotia, Part II-Antigonish, (Part 2) Guysborough, Pictou, and Cumberland Counties, by D. A. Murray, 1975, 155 pages. (\$6.50)

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- by Nova Scotia Department of Mines and Energy, 1981, 51 pages. (Microfiche \$1.00)
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- No. 13 Gold in Nova Scotia, by J. L. E. Bates, 1987, 35 pages. (\$5.00)
- NOTE: Program and Summaries will continue as part of our Report Series.

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Handbook for Companies Planning Offshore Drilling, by Nova Scotia Department of Mines, 1969, 23 pages. (\$0.50)

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An Act Respecting Exploration for the Underground Storage of Gas, by Nova Scotia Department of Mines and Energy, 1970, 6 pages. (\$1.00)

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- Folio of Geological Maps of Nova Scotia - includes Geological, Structural, Metamorphic, Classes of Mineral Deposits, Bouguer Gravity Anomaly and Magnetic Maps, by J. D. Keppie, G. K. Muecke, A. K. Chatterjee and others, scale 1:2 000 000, 1979. (\$1.00)
- Geological Highway Map of Nova Scotia by J. P. Bujak and H. V. Donohoe, Jr., scale 1:633 600, 1980. (Atlantic Geoscience Society, Special Publication Number 1). (\$3.50)
- A Map Book of the Province of Nova Scotia, scale 1:250 000, revised edition 1985 with index of geographical names, 39 pages. (\$9.00)
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- Geological Map of Nova Scotia, Metallic Mineral Occurrence Edition, by J. D. Keppie, D. J. Gregory, A. K. Chatterjee

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OFR 600 Metallic Mineral

Occurrences Map and Data Compilation, Eastern Nova Scotia - map sheets 11F, 11G, 11J, 11K, 11N, by M. Ponsford and N. A. Lyttle, 1984, 23 pages, 2 maps. (\$3.00)

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Preliminary Feasibility Study for an Underground Gold Mining Operation in Central Nova Scotia, by Nova Scotia Department of Mines and Energy, 1984, 62 pages, 2 maps. (\$5.00)

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Regional Lake Sediment Survey of the Meguma Zone, Southern Nova Scotia: New Analytical Data, by P. J. Rogers, M. A. MacDonald and D. W. Rigby, 1985, 65 pages, 2 maps. (\$5.00)

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- Scotia - map sheets 200, 20P, 21A, 21B, 21H, by M. Ponsford, G. Demont and N. A. Lyttle, 1985, 21 pages, 2 maps. (\$4.00)
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- NOTE: As of January 1986, all new open file reports will have a report number which will be assigned sequentially based upon the year the report is received by the Department.
- OFR 86-010 Study of Markets for Aggregate Materials accessible from Nova Scotia and New Brunswick, by ADI Limited. (\$10.00)
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- OFR 86-039 Agricultural Gypsum

- Project, by Peter Luke, 1986, 9 pages. (\$3.00)
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- (\$5.00)
- Geological Association of Canada/Mineralogical Association of Canada Guidebooks for Field Excursions (Fredericton, May 15-17, 1985).
- Trip No. 1 Appalachian Geotraverse (Canadian Mainland); J. D. Keppie, K. Currie, J. B. Murphy, et al. (\$15.00)
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- Trip No. 14 Lithostratigraphic, Physical Diagenetic and Economic Aspects of the Pennsylvanian Permain Transition Sequence of Prince Edward Island and Nova Scotia; H. W. van de Poll, J. R. Degrace, R. J. Ryan. (\$7.00)
- Basins of Eastern Canada and Worldwide Analogues, Programme with Abstracts, Basins of Eastern Canada and Worldwide Analogues Symposium, August 13-15, 1986, Halifax, Nova Scotia, 132 pages. (\$8.00)
- Atlantic Geoscience Society, Special Publication Number 4, Carboniferous-Jurassic Sedimentation and Tectonics: Minas, Cumberland and Moncton Basins, Nova Scotia and New Brunswick, by R. C. Boehner, J. H. Calder, D. C. Carter, H. V. Donohoe, Jr., L. Ferguson, R. K. Pickerill, and R. J. Ryan; a Field Trip Guidebook from the Basins of Eastern Canada and Worldwide Analogues Symposium, Halifax, August 1986, 122 pages. (\$8.00)

OTHER PUBLICATIONS AND MAPS AVAILABLE FOR PURCHASE

Malagash Salt, compiled and edited by
J. R. MacQuarrie, c.1975, 1981.

Atlantic Geoscience Society, Special Publication Number 5 (CSPG Memoir 12), Sedimentary Basins and Basin-Forming Mechanisms, edited by C. Beaumont and A. J. Tankard; from Basins of Eastern Canada and Worldwide Analogues Symposium, Halifax, August 1986, 527 pages. (\$70.00)

Contributions to the geology of the Meguma Terrane, Nova Scotia, edited by J. D. Keppie. Special issue of Maritime Sediments and Atlantic Geology, v. 22, no. 1, 1986, 135 pages. (\$10.00)

Quaternary Glaciations, Geomorphology and Sea Level Changes: Bay of Fundy Region; NATO Advanced Study Institutes Programme, International Advanced Course on Late Quaternary Sea Level Correlations and Applications, July 19 to 30, 1987, Halifax, Nova Scotia; Symposium Field Guide, 79 pages. (\$10.00)

The Mining Society of Nova Scotia 1887-1987, by D. Pigot. Published by the Mining Society of Nova Scotia, June 1987, 125 pages. (\$20.00) (Paperback: \$10.00)

¹ NOTE: Maps 82-6 to 82-9 may be purchased individually or as a set for \$25.00

² NOTE: Maps 85-3 to 85-6 may be purchased individually or as a set for \$10.00